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# Evaluation of Two Washrack Recycle Treatment Systems

by
Gary L. Gerdes
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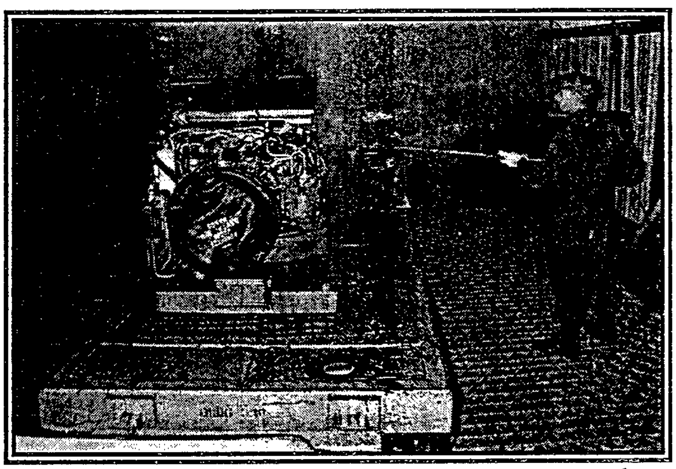
Edward Engbert





This study evaluated two commercial off-the-shelf washrack wastewater recycle treatment systems (a Landa and an RGF) to determine their applicability at Army facilities. The evaluation assessed the resource requirements for installation, operation, maintenance and repair, and also assessed the effectiveness of the treatment. The two systems were found to use somewhat similar treatment processes. After a 3-month evaluation for each system, the results of the evaluations were also similar. Both systems required significant resources for in-house labor and for service. Neither system could be operated continually in an automated closed loop mode. Removal of organics was inadequate, and slugs of organics (e.g., glycol and diesel fuel) passed through the systems. These systems would not be recommended for use at Army installations unless: (1) the cost to connect the washrack to sanitary sewer was exceptionally high, or sanitary sewer was not available, or (2) the washrack was in a water short area where recycle was required.

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# Foreword

This study was conducted for U.S. Army Environmental Center (USAEC) and supported by funds from AEC project EI6 Environmental Quality. Project managers at AEC were: Edward Engbert, Peter Stemniski, and Dennis Teefy, SFIM-AEC-ET.

The work was performed by the Troop Installation Operation Division (UL-T) of the Utilities and Industrial Operations Laboratory (UL), U.S. Army Construction Engineering Research Laboratories (USACERL), and by the Maryland Environmental Technology Demonstration Center (METDC), U.S. Army Aberdeen Test Center, Aberdeen Proving Ground. The efforts of the following Aberdeen Test Center and Aberdeen Proving Ground personnel were critical to the execution of this study: Ken Hudson (Test Director at the Aberdeen test site), Nick Retrossa and Richard Latham (mechanics responsible for maintenance activities on the two systems), Larry Erby and Donald Harris (Shop Managers), Glenn McClure and Max Conner (Sampling), Judy Galloway and Wayne Noble (Chemical Analysis), Angela Brown (Data Collection), Mike Kanowitz (APG Environmental Engineer), Opher Breslouer (Washrack Designer), and Lenett Henin (Reliability Analysis). Ken Hudson supervised all METDC efforts for this study. Joe Ondek is Chief of the METDC. The USACERL principal investigator was Gary L. Gerdes, CECER-UL-T. Walter J. Mikucki is Chief, CECER-UL-T; John T. Bandy is Operations Chief, CECER-UL; and Gary W. Schanche is the responsible Technical Director, CECER-TD. The USACERL technical editor was William J. Wolfe, Technical Resources.

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# 1 Introduction

## Background

U.S. Army tactical units must periodically wash their vehicles to prepare them for inspection and maintenance, and to maintain operational and mission readiness. However, many U.S. Army washracks are subject to being closed or operated at levels below mission requirements as a result of local, State, or Federal Clean Water Act requirements that regulate discharges to sewer systems or to the environment. The cost to operate washracks is increasing due to permit and monitoring requirements on washrack discharges.

To eliminate discharges, several Army facilities have purchased off-the-shelf, recycle treatment systems for their washracks, and many more facilities have requested funds to purchase these systems. Unfortunately, little was known about the actual maintenance requirements and treatment performance of these systems when used at Army washracks.

In response to a request from the U.S. Army Military District of Washington (MDW), the U.S. Army Environmental Center (AEC) initiated an investigation to determine if commercially available, closed loop wastewater treatment systems are applicable to Army requirements. AEC tasked the U.S. Army Construction Engineering Research Laboratories (CERL) with developing and performing an evaluation of two commercially available systems.

## Objective

The primary objective of this project was to apply a commercially available, closed loop wastewater treatment system to a U.S. Army application. The demonstration focused on the wastewater treatment system performance, installation and operational costs, and system maintenance requirements when used at a general-support, vehicle maintenance washrack with steam-cleaning operation.

## Approach

1. *Site Selection.* The U.S. Army Aberdeen Test Center (ATC) was chosen as the test site for this evaluation. ATC was an ideal location because the Center was in the process of constructing a new washrack with an RGF recycle treatment system, and because ATC's mission is to evaluate the performance and reliability of this same equipment. CERL tasked ATC with demonstrating two treatment systems: one manufactured by the RGF Environmental Systems, Inc., which had already been purchased, and the other manufactured by Landa, Inc. Landa provided the use of their system for this evaluation through a Memorandum of Agreement with ATC and AEC at no cost to the government. The new Building 338 Washrack Facility at ATC served as the test site.

2. *Evaluation Parameters.* The evaluation was to provide data on system installation, operation and maintenance, and wastewater treatment performance characteristics. Each system was to be operated for a period of 13 weeks, during which influent and effluent water quality, system characteristics, and operation and maintenance data were to be collected. The start date for the Landa test was 2 October 1996, with a 26 March 1997 conclusion. The start date for the RGF test was 10 July 1997, with a 2 December 1997 conclusion.

3. *System Selection.* Both the Landa and RGF systems were selected according to the manufacturers' representatives' recommendations. The Landa system evaluated was a Model CLP-7023A, designed to treat up to 15 gpm of washwater with high levels of suspended solids. The RGF system evaluated was the Model $ST^2$, designed to treat up to 25 gpm of high solids wash water.

# 2 System Descriptions

Both the RGF and Landa systems are fitted with various wastewater treatment components designed to remove contaminants typically found in wastewater from heavy vehicle maintenance washing. Each wastewater recycle treatment system tested was used to treat washwater from a single-bay washrack facility, and return it to the wash system for reuse. The entire washrack system consists of: the wastewater recycle treatment system, a raised platform wash area large enough to wash one large tracked vehicle, a solids collection pan underneath the wash area, a small sump pit with a pump to transfer water to the recycle system, a steam/power wash unit, and a building that houses the wash bay and all equipment.

The following paragraphs give detailed descriptions of the recycle systems being tested and of the washrack.

## Landa System — Model No. 7023A

### *General*

The Landa Model 7023A is a commercial off-the-shelf, self-contained, aboveground, washwater recycling system. The system is skid mounted and is fitted with various wastewater treatment components designed to remove contaminants typically found in heavy maintenance wash applications. Figure 1 shows the Landa system installed at the Aberdeen Test Center Building 338 washrack. Figure 2 shows the schematic of the Landa system being evaluated.

### *System Components*

The major components are: 600-gal clarifier tank (CLP), coalescing plates, oil skimmer, Carbasorb Filter, Process Water Manifold System, Cartridge Filters, Multi-Media Filter, control panel, oxidation reduction potential (ORP)/pH controller, Series 400 Ozonator and pump assembly, sludge disposal system, and sump pump (Landa pamphlet).

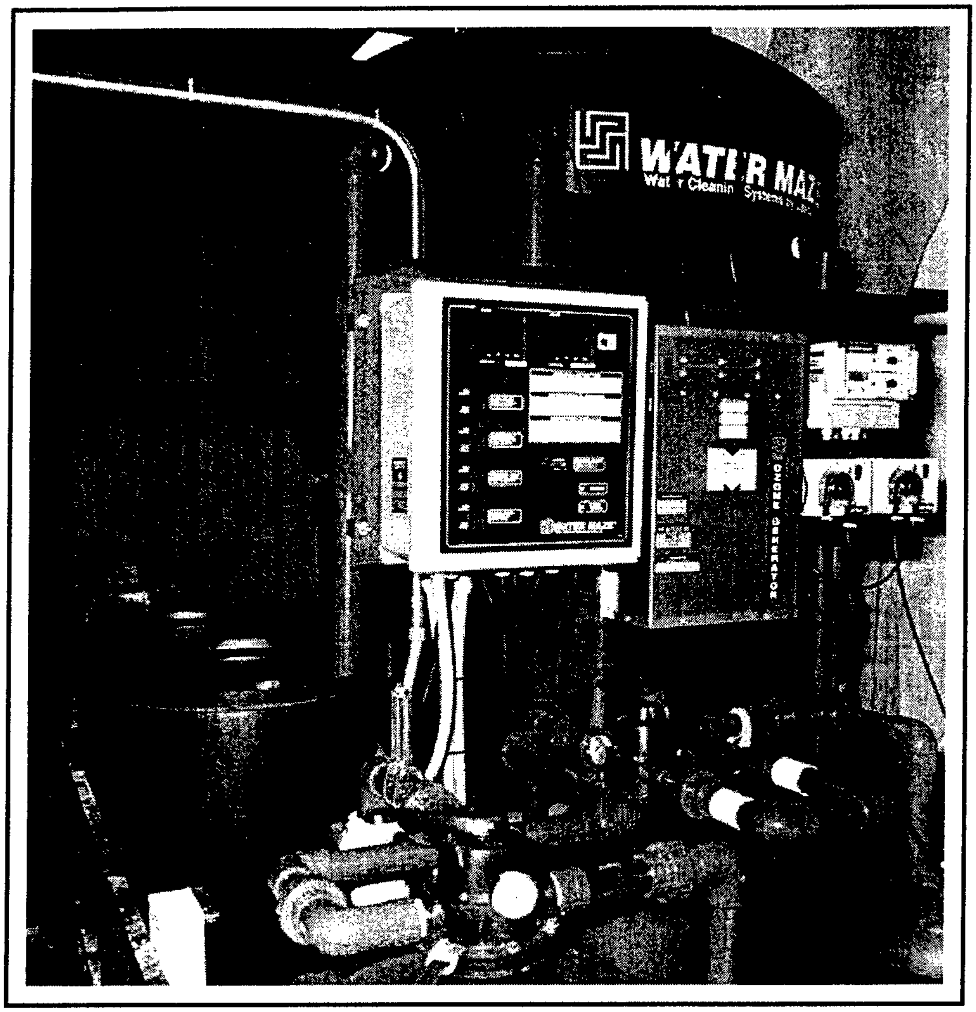
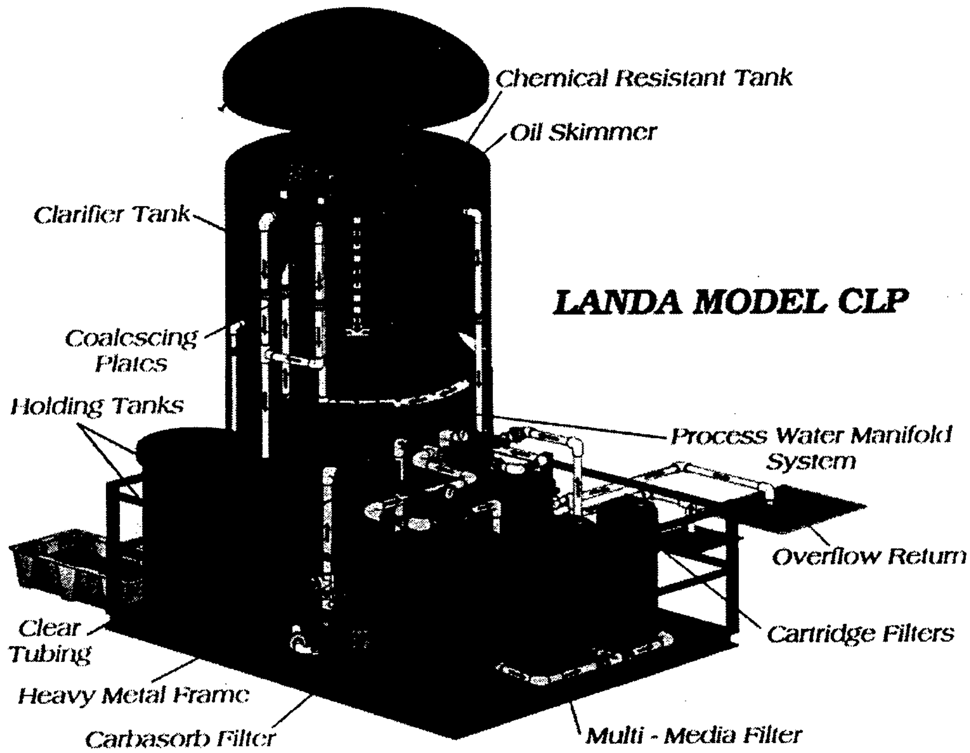



**Figure 1. Landa system in Building 338, Aberdeen Test Center.**

### *Operation*

The information in this section is adapted from material presented in a Landa pamphlet and Operator's Manual.

1. The 600-gal clarifier tank is constructed of polyethylene. The tank is the initial receiving point for the wastewater delivered from the washrack sump by a 1/2 horsepower sump pump. The wastewater is piped to the clarifier tank, and exits below the coalescing cones. The polypropylene coalescing cones have 340 sq ft of oil-coalescing surface area. The cones are angled at 55 degrees to enhance oil-water-solids separation. The solids collect in the bottom of the clarifier while the free oil is removed by a funnel shaped skimmer located at the top of the tank.




| Model | CLP-7021A | CLP-7022A | CLP-7023A | CLP-7032A | CLP-7033A |
|---|---|---|---|---|---|
| maximum flow | 15 gpm | 15 gpm | 15 gpm | 30 gpm | 30 gpm |
| Oil/Water Separator Capacity | 600 gal | 600 gal | 600 gal | 600 gal | 600 gal |
| Solids Separation Chamber | Yes | Yes | Yes | Yes | Yes |
| Electrical | 230V 1pH 20 amps | 230V 1pH 20 amps | 230V 1pH 20 amps | 230V 1pH 20 amps | 230V 1pH 20 amps |
| Filter Pump | 5 hp | 5 hp | 5 hp | 15 hp | 15 hp |
| Media Filter | NA | NA | 350 lb | NA | 350 lb |
| Sump Pump Submersible | 5 hp | 5 hp | 5 hp | 5 hp | 5 hp |
| Cartridge Filter | (1) 200 sq ft 20 micron | (2) 200 sq ft 20 micron | (2) 200 sq ft 20 micron | (2) 200 sq ft 20 micron | (2) 200 sq ft 20 micron |
| Carbon filter (degassed) | 200 lb | 300 lb | 200 lb | 300 lb | 200 lb |
| Transfer Pump Centrifugal | 5 hp | 5 hp | 5 hp | 2 hp | 2 hp |
| Oil Skimmer | Yes | Yes | Yes | Yes | Yes |
| Ozone Generator | Series 400 | Series 400 | Series 400 | Series 400 | Series 400 |
| Coalescing Pack | 340 sq ft | 340 sq ft | 340 sq ft | 340 sq ft | 340 sq ft |
| Clarified Holding Tank | 65 gal | 65 gal | 65 gal | 65 gal | 65 gal |
| Filtered Water Holding Tank | 65 gal | 65 gal | 65 gal | 65 gal | 65 gal |
| ORP/pH Controller | Standard | Standard | Standard | Standard | Standard |
| Electrical Panel | Nema 4 | Nema 4 | Nema 4 | Nema 4 | Nema 4 |
| Dimensions (LxWxH) | 96"x72"x110" | 96"x72"x110" | 96"x72"x110" | 96"x72"x110" | 96"x72"x110" |
| Net Dry Weight (approx) | 1820 lb | 1950lb | 2375 lb | 2320 lb | 2395 lb |

Note: We are constantly improving and updating our products. Consequently, pictures, features, and specifications may differ slightly from current models.

**Figure 2. Schematic of evaluated Landa system.**

2. The Series 400 Ozonator and pump assembly removes water from the clarifier tank, performs ozonation, and returns the water to the clarifier tank.

3. The ORP/pH controller electronically monitors the wastewater pH, and then automatically maintains proper pH and ORP (oxidation reduction potential) levels through chemical addition. The controller also serves as a chemical injection system for further enhancement of the system's cleaning capability.

4. The wastewater flows from the clarifier through the process water manifold system to a 65-gal vertical tank. The Process Water Manifold system consists of circular tubing containing holes to distribute the wastewater. The Process Water Manifold is located approximately 3 ft below the surface of the tank to avoid the discharge of free oil.

5. The wastewater is then processed through a series of filters. The Carbasorb Filter contains 200 lb of activated carbon. The Multi-Media Filter contains 350 lb of a blend of sand, gravel, and anthracite material. The Multi-Media Filter is designed to remove dirt and solids of a size greater than approximately 40 microns. The Cartridge Filter consists of tightly wound polyester elements with 200 sq ft of filtration area. The Cartridge Filter is designed to remove and collect solids larger than 5 to 20 microns. The Carbasorb Filter is designed to remove contaminants, such as pesticides, solvents, benzene, diesel fuels, acetone, and other hydrocarbons, as well as low levels of heavy metals, through adsorption. The processed water is then stored in a 65-gal Filtered Water Holding Tank for use by the steam/power wash cleaner unit.

6. Table 1 provides a brief description of wastewater flow through the treatment process.

**Table 1. Landa treatment sequence.**

| Sequence | Description |
|---|---|
| 1 | The 1/2 horsepower sump pump pushes the water from the sump and sends it to the CLP (clarifier, low profile). |
| 2 | The solids settle in the bottom of the cone in the clarifier. |
| 3 | The coalescing cones enhance separation of the oil and grease. |
| 4 | The 1/2 horsepower ozone pump takes water from the CLP, ozonates it, and returns it to the clarifier cone tank. |
| 5 | The skimmer removes the oil and sends it to the oil separation bucket (not shown). Excess water is returned to the washbay. |
| 6 | Partially treated water moves from the CLP to holding tank 1 through the series of filters to holding tank 2, and is then pumped to the pressure washer on demand. |

## RGF System — Model $ST^2$

### General

The RGF Model $ST^2$ is a commercial off-the-shelf, self-contained, aboveground, washwater recycling system. The system consists of various wastewater treatment components designed to remove contaminants typically found in heavy maintenance wash applications and a storage tank for the cleaned/treated water. The major components are Series I Tank, Series II Skid, and Storage Tank.

### System Components

1. The Series I Tank is of polyethylene construction and contains the following components: Aeration Tower, Oil Skimmer, Hydrocarbon Accumulator, Incline Polypropylene Tube coalescer, HCA-2 Absorber, Micro-Matrix coalescer, and Multi-Media Filter.

2. The Series II Skid contains the following components: Process Pump, $MS^3$ Membrane (optional, not used during this test), two CFC System Pumps, XL UV Catalytic Chamber, XL Turbohydrozone®, Chemical Injection Pump, pH Controller (optional), Hydrocarbon Absorber, Control Panel, and Coalescing Centrifugal Separator.

3. The Storage Tank is steel-reinforced, poly construction with a 550-gal capacity. The tank is fitted with a Manway and Tank Level Sight Tube. The tank is skid mounted.

### Operation

1. The information contained in this section is adapted from the Operations Manual for Model $ST^2$, Chapter 5, General Theory.

2. From the main sump, the waste stream enters the Coalescing Centrifugal Separator where a centrifugal circular motion forces the solids to separate to the sides and fall to the bottom of the centrifugal separator. The solids are bled continuously during operation. The Coalescing Centrifugal Separator contains an oil purge valve to remove free oils from the top of the centrifugal separator during routine maintenance.

3. The remaining waste stream then enters the Series I tank through the Inclined Tube Coalescer. The Inclined Tube Coalescer contains polypropylene

tubes inclined at 60-degree angles. The 60-degree incline causes small oil globules to coalesce and form larger oil drops, which float to the surface. The free oil is then removed by the Oil Skimmer. Solids collect in the bottom of the first compartment of the Series I tank and are flushed during regular maintenance.

4. The second compartment of the Series I tank contains a solids filter and oil absorber. The weight of the water that collects in the first compartment pushes the water up through the Solids Separation Grid, which attracts and settles small solids that pass through the Inclined Plate Coalescers. The HCA-2 Hydrocarbon Absorber then absorbs oils. The water then overflows into the third compartment.

5. The third compartment contains the Multi-Media Filtration Bed. The water is pulled through the filter media by the Process or Transfer System. As it passes through the filter, it flows through a series of media. The first layer, the Volcansorb Layer, is a solids filter. In the second layer, the water is drawn through the Ion Exchange Media Layer, where inorganic materials (heavy metal ions) are removed. The third layer is the Carbon Layer, where oils, odors, and organics are adsorbed. Finally, the water flows through another layer of Volcansorb. The water then leaves the Series I Tank and enters the Process and Control System.

6. The water enters the Process System of the Series II equipment skid by the suction of the Process Pump. The water is filtered through the two primary Polishing Filters of the system down to the 10-micron range before passing it on to the MS$^3$ Membrane System. The third filter is the Back-Up Supply Filter which is only activated by a low level signal in the Series III storage tank, which opens the SB-7 solenoid valve and then supplies this water to the Control Panel. From the Process System, the water originally entered the MS$^3$ Membrane System. RGF indicated the MS$^3$ Membrane System had become optional equipment on the ST$^2$ after the installation's purchase. RGF believed the membrane system would not be necessary to provide adequate quality of water for our application. MYCO, the RGF service representative, indicated that maintenance of the MS$^3$ required a lot of time, including chemical cleaning. MYCO was tasked by RGF to retrofit the test unit and bypass the membrane, at no cost to the Government.

7. The MS$^3$ Membrane System (not used in this evaluation) consists of an ultrafiltration technique that filters out particles larger than 500,000 molecular weight, and allows clean water, soaps, and chemicals to pass through. The permeate, which is now called "product water," leaves the

membrane housing and is stored in the Series III storage tank. The remaining water, called reject water, runs along the outside of the membrane and exits out the side of the housing to be sent back to the Series I tank. The membranes require maintenance by backflushing as well as periodic cleaning using a chemical treatment procedure.

8. The supply header comprises a manifold of piping and valves that allow the operator to select the water source to be supplied to the wash equipment. The operator may select either wash- or rinsewater to be delivered to the wash equipment. Rinsewater is typically municipally supplied tap water and is used to replace water lost to evaporation and dragout. Recycled washwater will come from the Continuous Flow Control (CFC) System, which is the primary source or from municipal water filtered by the No. 3 Back-Up Polish Filter.

9. The CFC System consists of the two CFC Pumps, the $UV/O_3$ Chamber, and hydrogen peroxide injection. This CFC pump continuously circulates water through the Catalytic Oxidation Process ($CO_3P$), providing disinfected recycled water at moderate supply pressure to the washrack or sending disinfected water back to the head end of the RGF unit. Continuously recycling disinfected water back through the unit minimizes biological growth within the RGF system. The CFC refers to the mechanism for the hydraulic delivery system, and $CO_3P$ refers to the chemical and photochemical process for water treatment.

10. Two 1/6 horsepower, CFC centrifugal circulation pumps move the processed water from the storage tank to the Supply Header and through the $CO_3P$ system.

11. The Catalytic Oxidation Process is designed to reduce the biological oxygen demand (BOD) and chemical oxygen demand (COD) of the recycled water and to disinfect the recycled water. This is accomplished through contact with hydrogen peroxide and ozone in the presence of ultraviolet light (UV). UV light (catalyst and oxidizer) in the chamber excites the ozone (oxidizer) and hydrogen peroxide (oxidizer) to cause them to react faster in the aqueous solution. The UV light and the oxidizers kill living organics such as bacteria and algae. The ozone and peroxide oxidize organics in the water, thus lowering the BOD and COD. The Catalytic Oxidation Process is accomplished by the CFC System, which transfers the water from the tank, passing it by the hydrogen peroxide injection and ozone injection and through the $UV/O_3$ Catalytic Chamber, and returning it back to the tank.

12. Chemical Injection Pumps are located within the control panel and are used to add hydrogen peroxide to help control algae, bacteria, and odor.

13. The UV/$O_3$ Catalytic Chamber contains the mechanism to produce ozone gas, which is venturi-injected in the CFC system to prevent bacteria or algae growth. The chamber also produces UV light, used to destroy organics and excite ozone and hydrogen peroxide spurring the Catalytic Oxidation Process as the water passes through the chamber.

14. Figure 3 shows the RGF Model $ST^2$ installed at the Aberdeen Test Center Building 338 washrack. Figure 4 shows a schematic of the RGF system evaluated in this study.

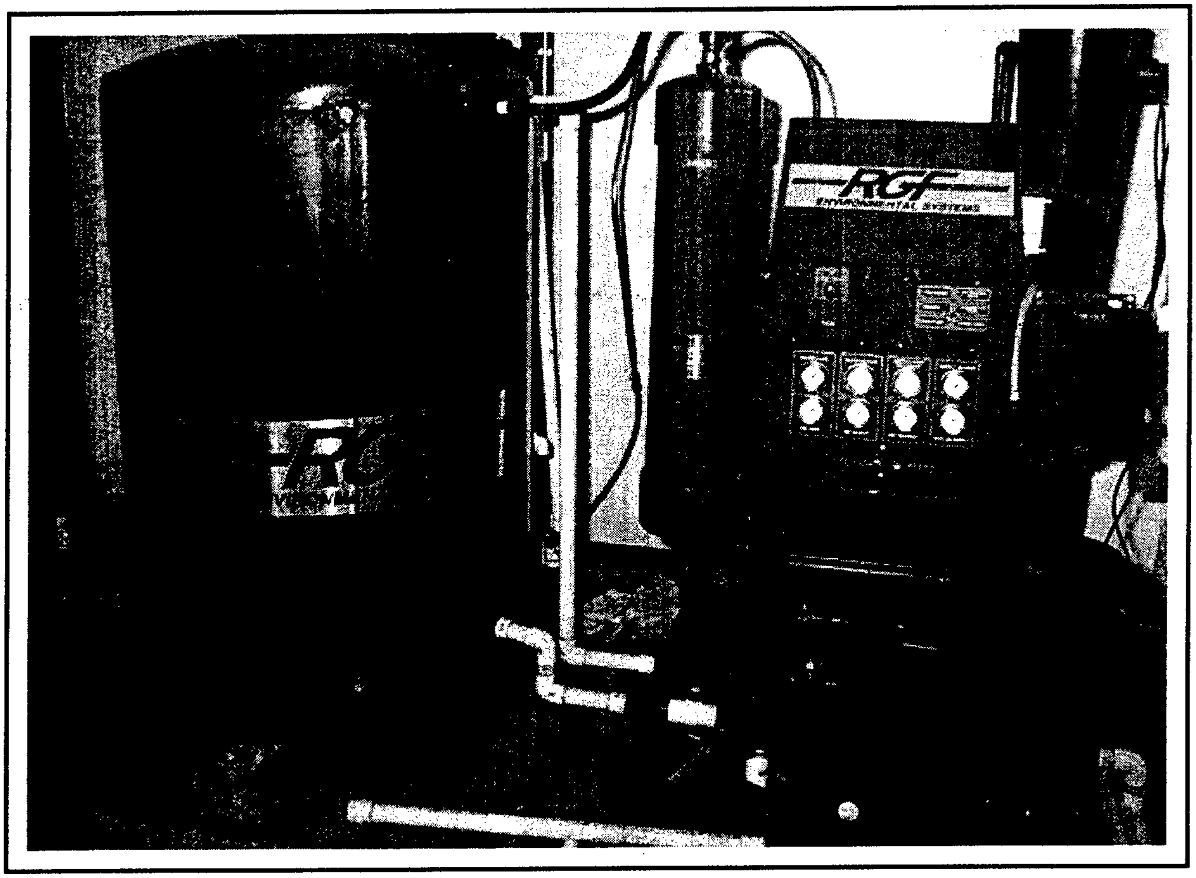
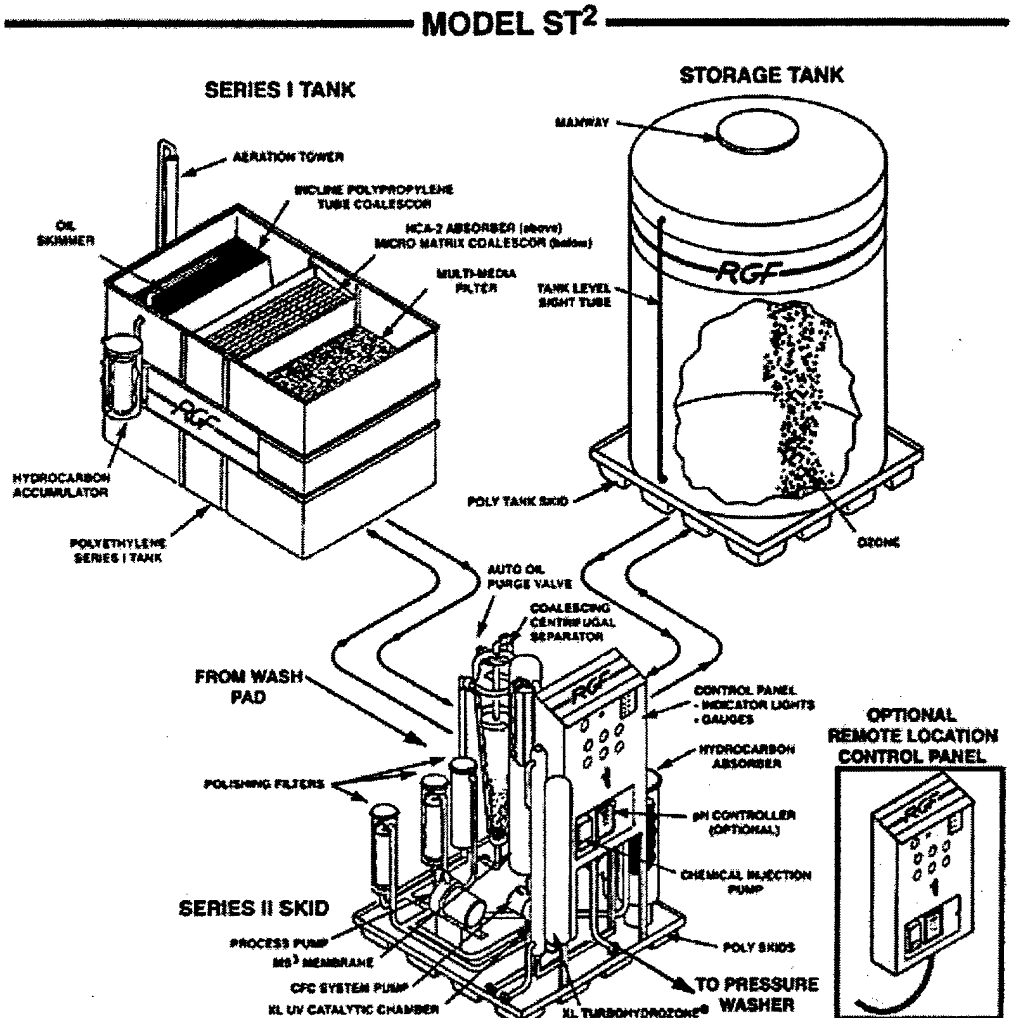


**Figure 3. RGF system in Building 338 washrack, Aberdeen Test Center (Series I tank not shown.**




| | | | |
|---|---|---|---|
| DIMENSIONS: SERIES I TANK | 4'-4"W X 6'L X 6'H | STORAGE TANK | 500 GAL. POLY TANK |
| SERIES II SKID | 4'W X 4'L X 7'H | HYDROCARBON ACCUMULATOR | 7 GAL. POLY TANK |
| STORAGE TANK | 4'W X 4'L X 6'-6"H | COALESCING CENT. SEPARATOR | POLY HOUSING |
| FLOW RATE | 1 - 25 GPM | INCLINED TUBE COALESCOR | POLY-PRO INCLINED GRID |
| ELECTRICAL REQUIREMENTS | 220V - 30 AMP - SINGLE PHASE | MICRO-MATRIX COALSECOR | POLY INCLINED GRID FILTER |
| WEIGHT (APPROX.) | 1,500 LBS. | MULTI-MEDIA FILTER | 800 LBS. MIXED MEDIA |
| CFC SYSTEM PUMP | 1/6 h.p. CIRCULATION | AUTO OIL SKIMMER | PVC ADJUSTABLE |
| PROCESSING PUMP | 1 1/2 h.p. CENTRIFUGAL | HYDROCARBON ABSORBER | POLY HOUSING & HCA-3 FILTER |
| CHEMICAL INJECTION PUMP | PERISTALTIC METERING | POLISHING FILTER | POLY-PRO HOUSING & 1 M FILTER |
| VALVES | PVC BALL & ELECTRIC SOLENOID | XL UV CATALYTIC CHAMBER | KRYPTON / QUARTZ |
| TUBING | UV PROTECTED PVC & POLY | XL TURBOHYDROZONE® | 50 ppm CONT. OZONE DISCHARGE |
| SERIES I TANK | 750 GAL. POLY TANK | MOLECULAR SEPARATION MEM. | 500,000 MOLECULAR WEIGHT |

MANUFACTURER RESERVES THE RIGHT TO MAKE CHANGES WITHOUT NOTICE.

**Figure 4. Schematic of evaluated RGF system.**

## Washrack Facility

The Closed Loop Washrack Facility located adjacent to Building 338 was selected to serve as the test site for the two wastewater recycle treatment systems. The facility was constructed during the months of July and August 1996 and was used for testing from October 1996 through December 1997.

The Washrack Facility consists of an enclosure, solids removal pan, mechanical room, wastewater treatment system, and steam/power wash cleaning unit. The facility has installation electrical power and potable water service. The washrack was originally constructed for complete recycle of washwater and had no provisions for discharge to the environment or to sanitary sewer. Because the recycle treatment systems could not be operated without some discharge, a sanitary sewer connection was added to the washrack facility to provide an emergency overflow of excess treated washwater to the sanitary sewer.

The washrack also provided pretreatment in the form of solids removal prior to pumping washwater to the recycle systems. The wash area was constructed above a sloped drain pan that served as a solids settling and collection basin. Total volume of water and solids contained by this basin is about 45 cu ft. Figure 5 shows an M1 powerpack being washed at the Building 338 washrack. Washing was done with a Alkota steam/hot water washer. No soaps or detergents were used in the washing process.

## Personnel Training

Training was provided to ATC personnel by the manufacturer service representatives. The training was described by the representative as typical of new equipment training provided by the manufacturers to other Department of Defense (DOD) purchasers. Thirty-five mechanics were trained to use the Landa equipment. They received a 20-minute overview of typical operation and scheduled maintenance actions. Twenty-five mechanics received a 15-minute overview on the RGF system.

While a large number of mechanics attended the training, only three mechanics were actually assigned to do maintenance. It is recommended that only a few persons be allowed to perform maintenance in order to maintain their skills and provide continuity.

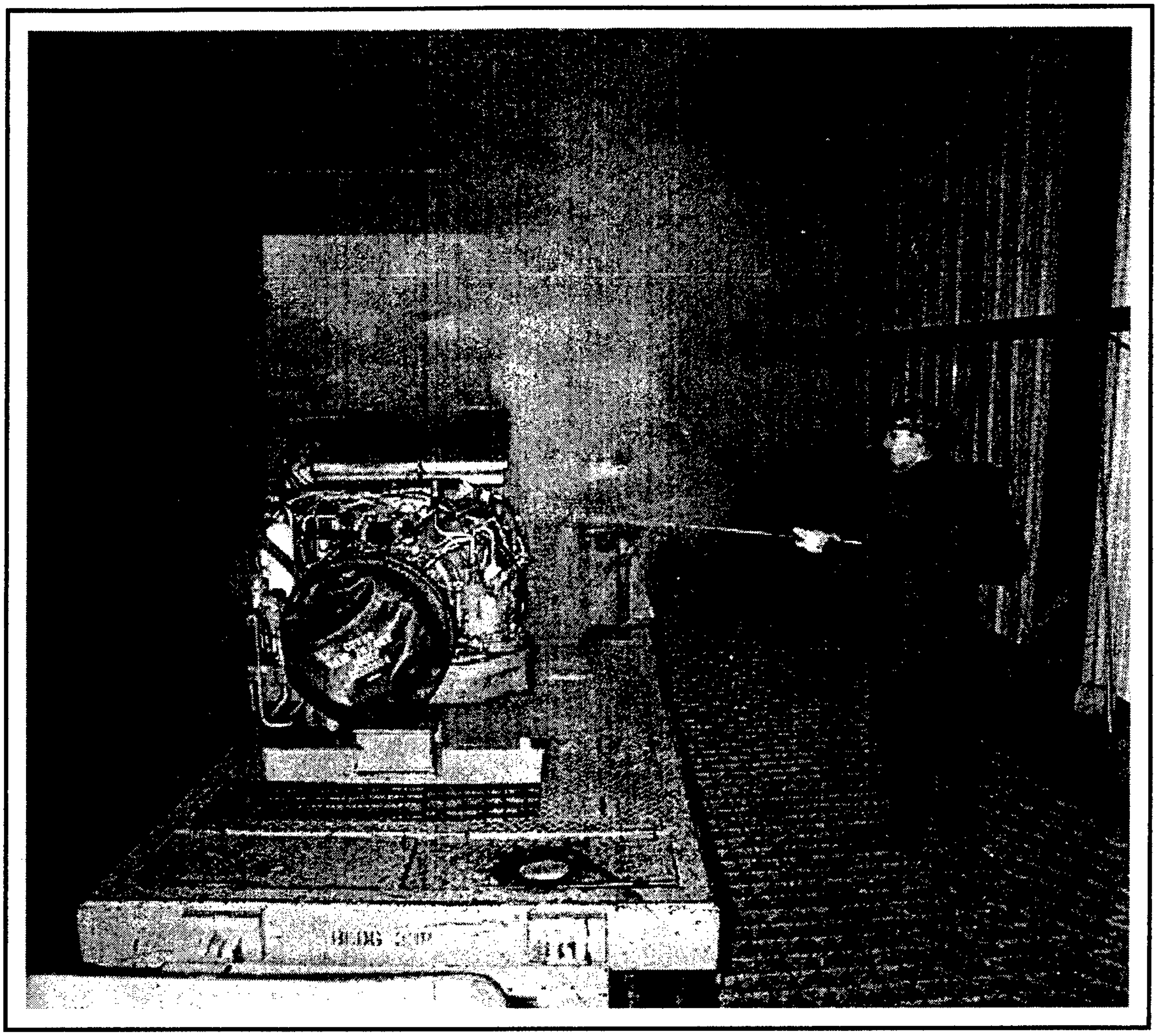


**Figure 5. Washing equipment at Building 338 washrack.**

# 3 Data Collection

## Initial Inspection

An initial inspection was performed on each washwater recycle system before start-up. The purpose of the initial inspection was to ensure that: the systems had not been damaged in shipment, the associated parts were inventoried, the systems were in proper electrical, physical, and mechanical condition as verified by the manufacturers or their representative, and that major subsystems and components were identified and serialized. A pretest system check was performed by conducting a wash mission.

## Reliability and Maintainability

Data was collected for the duration of the project to support a reliability and maintainability assessment of the two commercial wastewater recycle treatment systems. Daily operational data was collected through a usage log. The log recorded data such as: item being cleaned, principal contaminants (15W40 oil, DF-2, hull sludge, etc.), wash time, and operator comments. Each system usage was documented. Meter readings were recorded at the conclusion of each shift. The following meters were used: wastewater treatment hour meter (system component), make-up water volume meter, wastewater treated volume meter, power wash activation hour meter, and a steam cleaner activation hour meter.

Scheduled maintenance activities and frequencies were limited to those prescribed in the manufacturer's operation and maintenance manuals, or as otherwise recommended by the manufacturer. Data collected included the following: a description of the maintenance activity, clarity of the manual in defining necessary actions, need for specialized tools, general complexity of the repair, and time taken for each maintenance or repair. Typical analytical products derived from the data include the following: mean time to repair, mean time between failures, and maintenance ratio (maintenance hours/operating hours). Each unscheduled maintenance/repair activity was documented by a Test Incident Report (TIR). Specific TIRs are referenced in other sections of this report.

## Wastewater Treatment Performance

The treatment performance was determined by measuring the quality of the recycled water periodically during the course of the system evaluations. Grab samples were taken from the treated water storage tank. Treatment is considered successful if the concentration of pollutants in the recycle water remain below the levels allowed for discharge to the environment.

### *Treated Water Stored for Reuse*

The quality of water available for reuse was analyzed weekly. The samples were drawn from the treated water storage by a representative of the Aberdeen Test Center's Environmental Office.

### *Make-up Water Quality*

A grab sample of the make-up supply water was sampled and analyzed for pH, DO, COD, TSS, TDS, metals, and total coliforms. The make-up water (tap water) was sampled and analyzed at the initiation of testing.

*Analytical Methods.* The analysis methods used for determining the recycle water quality are as follows:

- Total Petroleum Hydrocarbons/Oil and Grease - EPA 418.1 (sample 20022 - EPA Method 1664)
- Polynuclear Aromatic Hydrocarbons (PAH) - EPA 610
- Ethylene Glycol - CADSOP22.2
- pH - EPA 150.1
- Alkalinity - SM 2320
- Hardness - Calcium and Magnesium - EPA 200.7
- Total Hardness - SW 2340C
- Chemical Oxygen Demand (COD) - EPA 410.4
- Total Coliform - SW 9221B (MPN)
- Metals - EPA 200.7
- Temperature - EPA 170.1
- Dissolved Oxygen (DO) - SW 4500-O
- Total Suspended Solids (TSS) - EPA 160.2
- Total Dissolved Solids (TDS) - EPA 160.1
- Total/Free Chlorine - SW 4500-CL (DPD Colorimetric).

## Inspections

Daily, weekly, and monthly inspections were conducted in accordance with the manufacturer's operating manual, and at the end of testing for each system. There were some minor variances and specifications the manufacturers added to the manual procedures.

# 4 Observations

## System Operation, Maintenance, and Repair

### *Usage of the Landa System*

The test period for the Landa system was from 2 October 1996, through 26 March 1997. During that period, the washrack was used 96 days, during which 275 items were washed. The meter on the steam cleaner showed it was in use for 254.3 hours. Table 2 and Figure 6 show the types of items being washed, and the number of minutes of wash time according to usage logs kept by the operators.

**Table 2. Washrack usage during Landa test.**

| Item | Total Wash Time (Minutes) |
|---|---|
| Hull | 4180 (32%) |
| Storage Drums | 3705 (28%) |
| Powerpack | 1995 (15%) |
| Wheeled Vehicle | 1649 (12%) |
| Wh. Veh. Powertr. | 1224 (9%) |
| Misc. or Unknown | 500 (4%) |
| **Total** | **13253** |

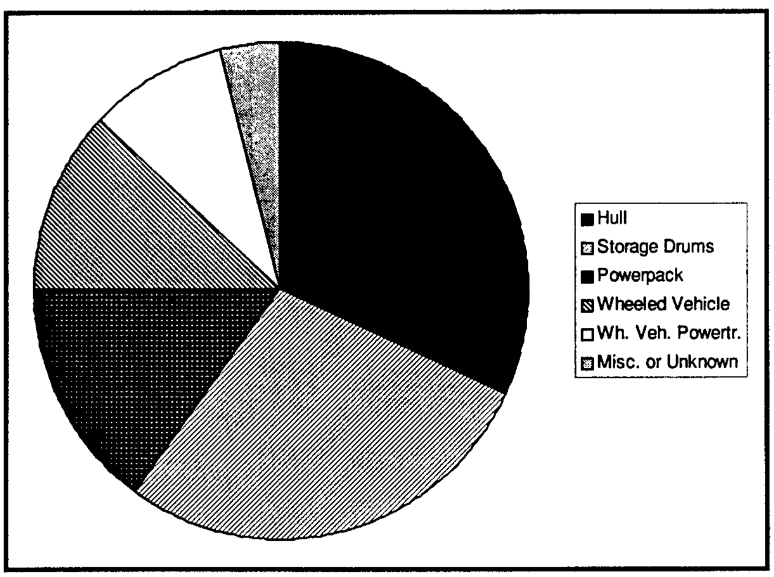



**Figure 6. Washrack usage during Landa test.**

The flow from the washer was measured at 4.6 gal per minute (gpm). The total volume of water used for washing during the test is about 61,000 gal, or about 635 gal per wash day.

For almost half of the items, the primary contaminant removed during washing was dirt and mud, according to operators logs. The primary contaminants recorded for the other items washed were: oil, anti-freeze, fuel, grease, and hydraulic fluid.

### *Usage of the RGF System*

The test period for the RGF system was from 10 July 1997, through 2 December 1997. During the 87 days the washrack was used, 184 items were washed. The meter on the steam cleaner showed it was in use for 252.2 hours. Table 3 and Figure 7 show the usage of the washrack during the RGF test period.

The flow from the washer was measured at 4.6 gpm. The total volume of water used for washing during the test is about 47,700 gal, or about 550 gal per wash day.

**Table 3. Washrack usage during RGF test.**

| Item | Total Wash Time (Minutes) |
|---|---|
| Hull | 4609 (44%) |
| Wheeled vehicle | 1767 (17%) |
| Powerpack | 987 (10%) |
| Storage drums | 415 (4%) |
| Misc. or unknown | 2588 (25%) |
| **Total** | **10366** |

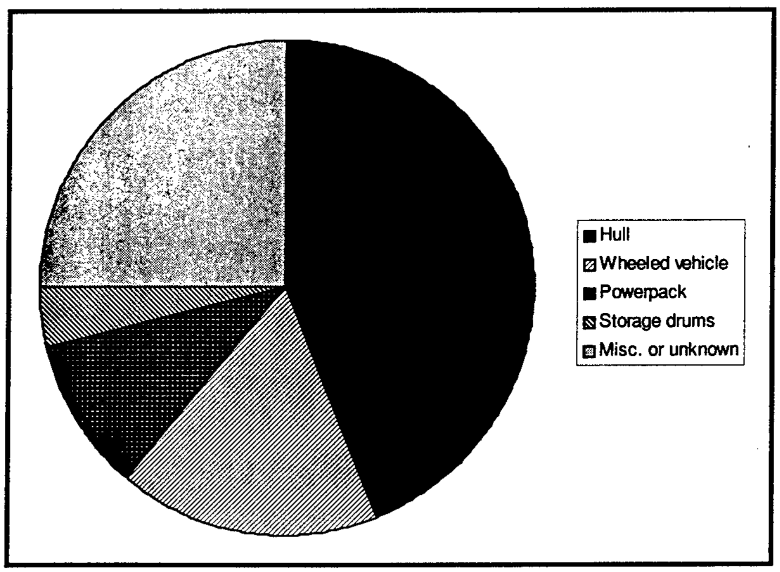



**Figure 7. Washrack usage during RGF test.**

According to operators logs, the primary contaminant for over half of the items removed during washing was oil. The primary contaminants recorded for the other items washed were: anti-freeze, dirt and mud, fuel, grease, and hydraulic fluid.

### *Make-up Water*

Considerably more water was added to the Landa system than to the RGF system (23,710 gal of make-up water were added to the Landa system, and 7,056 gal were added to the RGF system). Problems with the automatic make-up water function during the Landa test caused a large amount of water to be discharged. This did not happen during the RGF test because the automatic make-up water addition function was disabled at the beginning of the test. Make-up water was added manually to the RGF system. Table 4 shows the recorded amounts of make-up water added to the systems.

The decision to disable the automatic make-up water addition function on the RGF system was made by the washrack operators. This was allowed for two reasons: (1) the operators wished to avoid a repeat of the excess water discharge problems experienced with the Landa system, and (2) the RGF system has a much larger clean water storage reservoir than the Landa system, making the need for immediate make-up water addition unnecessary.

The Landa water storage tank held only 65 gal of water, while the RGF storage tank held 500 gal. The small Landa tank contributed to the problem of balancing the water in the system. At 4.6 gpm, it only takes 14 minutes of washing to empty the storage tank. Flow from the washer back to the recycle system is inherently slow, therefore the Landa storage tank was often empty before washwater could be pumped back to the treatment system.

**Table 4. Make-up and discharge volume.**

| System | Date | Make-Up Water Added (gal) between sampling events | Overflow (gal) between sampling events | Related ATC Test Incident Report Numbers |
|---|---|---|---|---|
| Landa | 11/4/96 | 8039.8 | 0 | 9 |
| Landa | 11/12/96 | 1316.4 | 0 | |
| Landa | 11/18/96 | 289.2 | 0 | 22 |
| Landa | 11/25/96 | 776 | 398.7 | 32 |
| Landa | 12/2/96 | 849.9 | 508.1 | |
| Landa | 12/9/96 | 987.4 | 1184.3 | |
| Landa | 12/16/96 | 873.5 | 725.2 | 44 |
| Landa | 12/23/96 | 475 | 265 | |
| Landa | 12/29/96 | 173.8 | 88.9 | 45 |
| Landa | 1/6/97 | 144.8 | 0.2 | |

| System | Date | Make-Up Water Added (gal) between sampling events | Overflow (gal) between sampling events | Related ATC Test Incident Report Numbers |
|---|---|---|---|---|
| Landa | 1/13/97 | 329 | 299.5 | |
| Landa | 1/21/97 | 401.2 | 148.3 | 52 |
| Landa | 1/27/97 | 2403.8 | 3301.6 | 58,59 |
| Landa | 2/26/97 | 4476.1 | 9798.8 | 60,61,62,65 |
| Landa | 3/25/97 | 2174.1 | | 67,75,78,79,68 |
| | Total | 23,710 | 16,719 | |
| RGF | 7/14/97 | 1102.3 | >400 | 84,85 |
| RGF | 7/21/97 | 74.5 | | 94,95 |
| RGF | 7/28/97 | 54.5 | | |
| RGF | 8/4/97 | 630.6 | >960 | 86 |
| RGF | 8/18/97 | 540.9 | >300 | 87 |
| RGF | 8/25/97 | 702.1 | | |
| RGF | 9/2/97 | 587.4 | | |
| RGF | 9/8/97 | 213 | | |
| RGF | 9/16/97 | 1046.7 | >300 | 89 |
| RGF | 9/22/97 | 26.2 | | |
| RGF | 9/29/97 | 1263.2 | | |
| RGF | 10/6/97 | 815.39 | | |
| | **Total** | **7,056** | **>1960** | |

Notes:
1. Make-up water manually added throughout RGF system operation
2. RGF system overflows were estimated based on water added (deleted repeated text) to refill system to operating levels

When the tank emptied during a wash event, the pump supplying water to the steam cleaner shut off. This caused the steam cleaner to run without water, creating a possibility of damage to the steam cleaner. When the Landa storage tank was empty, make-up water was added to the storage tank automatically from the tap. The make-up water coupled with the water temporarily detained by the solids removal pan and wash item resulted in the entire system having excess water. A much larger storage tank would have served to equalize the flow, and prevented the water balance problems.

It is recommended that the storage tank on any recycle system contain enough water for at least 1 hour of washing. For this evaluation, the storage tank should have been at least 276 gallons (4.6 gpm x 60 min). (Note that it is also important not to oversize the storage tank. The requirement for disinfection chemicals is somewhat proportional to the size of the storage tank. For this evaluation, it may have been better to have a smaller tank in the RGF system.)

### *Water Discharged from the Systems*

Again, because of the make-up water addition problem mentioned above, considerably more water was discharged from the Landa system than from the RGF system (16,719 gal of water were discharged [overflow] during the Landa test, and more than 1,960 gal were discharged during the RGF test). Table 4 shows the recorded amounts of water discharged from the systems.

### *Scheduled Maintenance*

During the Landa test, a total of 39.7 work-hours were spent on scheduled daily, weekly, and monthly maintenance actions. Approximately 24.8 minutes per workday were spent on scheduled maintenance. Table 5 shows the amount of time logged for scheduled maintenance on the Landa system.

During the RGF test, 35.4 work-hours were spent on scheduled maintenance actions. The operators spent approximately 24.4 minutes per day on scheduled maintenance. Table 6 shows the amount of time logged for scheduled maintenance on the RGF system. The time recorded in the "weekly" column also includes daily tasks performed at the same time.

The 25 minutes per day for the Landa system scheduled maintenance and 24 minutes per day for the RGF system scheduled maintenance is a reasonable amount of time, and does not severely impact productivity. Most of the maintenance tasks are repetitive and require only one person. It is recommended that only two or three workers be assigned to perform scheduled maintenance to prevent constant retraining, and to protect the system from workers with good intentions from inadvertently doing damage.

Table 5. Time spent on Landa scheduled maintenance.

| Date | Daily (minutes) | Weekly (minutes) |
|---|---|---|
| 11/7/96 | NR* | |
| 11/8/96 | NR | |
| 11/12/96 | 25 | |
| 11/19/96 | 36 | |
| 11/25/96 | | 144 |
| 11/26/96 | 19 | |
| 11/27/96 | 11 | |
| 12/2/96 | | 9 |
| 12/3/96 | 30 | |
| 12/4/96 | 12 | |
| 12/5/96 | 30 | |
| 12/6/96 | NR | |
| 12/9/96 | NR | |
| 12/10/96 | 11 | |
| 12/13/96 | NR | |
| 12/14/96 | 15 | |
| 12/16/96 | NR | |
| 12/17/96 | 15 | |
| 12/21/96 | 10 | |
| 12/23/96 | | 60 |
| 12/24/96 | 31 | |
| 12/26/96 | 30 | |
| 12/27/96 | 30 | |
| 12/28/96 | 8 | |
| 12/30/96 | | 30 |
| 12/31/96 | NR | |
| 1/2/97 | 10 | |
| 1/4/97 | 10 | |
| 1/6/97 | | 47 |
| 1/7/97 | NR | |
| 1/8/97 | 25 | |
| 1/9/97 | 22 | |
| 1/10/97 | 21 | |
| 1/11/97 | 24 | |
| 1/13/97 | | 74 |
| 1/14/97 | 71 | |
| 1/15/97 | 17 | |
| 1/16/97 | 25 | |
| 1/17/97 | 30 | |
| 1/21/97 | | 35 |
| 1/22/97 | 16 | |
| 1/23/97 | 19 | |
| 1/24/97 | 44 | |
| 1/25/97 | 75 | |
| 1/27/97 | | 45 |
| 1/28/97 | 30 | |
| 1/29/97 | 25 | |
| 1/30/97 | 35 | |
| 2/4/97 | | 120 |
| 2/5/97 | 30 | |
| 2/6/97 | 30 | |
| 2/7/97 | 25 | |
| 2/24/97 | | 20 |
| 2/26/97 | 25 | |
| 2/27/97 | 45 | |
| 3/3/97 | | 50 |
| 3/4/97 | 60 | |
| 3/5/97 | 50 | |
| 3/6/97 | 45 | |
| 3/7/97 | 22 | |
| 3/10/97 | | 30 |
| 3/11/97 | 70 | |
| 3/12/97 | 30 | |
| 3/13/97 | 30 | |
| 3/14/97 | 20 | |
| 3/17/97 | | 44 |
| 3/18/97 | 40 | |
| 3/19/97 | 40 | |
| 3/20/97 | 45 | |
| 3/21/97 | 50 | |
| 3/22/97 | 80 | |
| 3/24/97 | | 45 |
| 3/25/97 | 40 | |
| 3/26/97 | | 40 |
| Totals | 1589 | 793 |

*NR = Service completed, but time not recorded.

Table 6. Time spent on RGF scheduled maintenance.

| Date | Daily (minutes) | Weekly (minutes) | Monthly (minutes) |
|---|---|---|---|
| 6/19/97 | 25 | | |
| 6/19/97 | | 84 | |
| 6/19/97 | | | 16 |
| 7/2/97 | 15 | | |
| 7/2/97 | | 38 | |
| 7/9/97 | 15 | | |
| 7/10/97 | 10 | | |
| 7/11/97 | 10 | | |
| 7/15/97 | 20 | | |
| 7/17/97 | 16 | | |
| 7/22/97 | 8 | | |
| 7/23/97 | 19 | | |
| 7/24/97 | 15 | | |
| 7/28/97 | 8 | | |
| 7/29/97 | 9 | | |
| 7/31/97 | | 30 | |
| 7/31/97 | | | 32 |
| 8/5/97 | | | 45 |
| 8/7/97 | 13 | | |
| 8/13/97 | 25 | | |
| 8/21/97 | 25 | | |
| 8/25/97 | 25 | | |
| 8/26/97 | 21 | | |
| 8/27/97 | 5 | | |
| 8/28/97 | 8 | | |
| 9/2/97 | 15 | | |
| 9/3/97 | 35 | | |
| 9/3/97 | | 50 | |
| 9/4/97 | 30 | | |
| 9/5/97 | 8 | | |
| 9/8/97 | 5 | | |
| 9/9/97 | 5 | | |
| 9/10/97 | 5 | | |
| 9/11/97 | 5 | | |
| 9/11/97 | | 120 | |
| 9/13/97 | 180 | | |
| 9/15/97 | 150 | | |
| 9/16/97 | 40 | | |
| 9/18/97 | 5 | | |
| 9/19/97 | | 105 | |
| 9/22/97 | 15 | | |
| 9/23/97 | 60 | | |
| 9/24/97 | 5 | | |
| 9/25/97 | 20 | | |
| 9/29/97 | 15 | | |
| 9/30/97 | 10 | | |
| 10/1/97 | 5 | | |
| 10/2/97 | 5 | | |
| 10/3/97 | 5 | | |
| 10/6/97 | 10 | | |
| 10/7/97 | 5 | | |
| 10/8/97 | 10 | | |
| 10/14/97 | 35 | | |
| 10/15/97 | 30 | | |
| 10/15/97 | | 105 | |
| 10/16/97 | 6 | | |
| 10/17/97 | 5 | | |
| 10/18/97 | 20 | | |
| 10/20/97 | 10 | | |
| 10/21/97 | 10 | | |
| 10/22/97 | 5 | | |
| 10/23/97 | 5 | | |
| 10/25/97 | 5 | | |
| 10/27/97 | 5 | | |
| 10/28/97 | 2 | | |
| 10/28/97 | | 60 | |
| 10/29/97 | 5 | | |
| 10/30/97 | 15 | | |
| 10/31/97 | 15 | | |
| 11/3/97 | 4 | | |
| 11/4/97 | 7 | | |
| 11/5/97 | 8 | | |
| 11/6/97 | 9 | | |
| 11/8/97 | 35 | | |
| 11/10/97 | 20 | | |
| 11/12/97 | 15 | | |
| 11/13/97 | 10 | | |
| 11/17/97 | 20 | | |
| 11/18/97 | 7 | | |
| 11/19/97 | 5 | | |
| 11/20/97 | 15 | | |
| 11/20/97 | | 75 | |
| 11/24/97 | 5 | | |
| 11/25/97 | 7 | | |
| 11/26/97 | 15 | | |
| 12/1/97 | 15 | | |
| 12/2/97 | 8 | | |
| 12/2/97 | | 35 | |
| 12/2/97 | | | 10 |
| Totals | 1318 | 702 | 103 |

### *Unscheduled Maintenance*

All unscheduled maintenance tasks were recorded using Test Incident Reports (TIRs), a form used by Aberdeen Test Center when evaluating equipment. A list of the TIR related to unscheduled maintenance is provided in Appendix A. For the Landa test, 32 TIRs were written for unscheduled maintenance. Those actions required a total of 19.8 hours. For the RGF test, 10 TIRs were written requiring a total 13.1 hours. Many actions reported on TIRs were simply adjustments made to the recycle systems and required little or no labor. Other actions reported required shutdown of the equipment. Those are discussed in more detail in the following section, "Reliability" (p 31).

### *Maintainability – Landa*

The operational and maintenance manual was adequate in providing figures illustrating differing views of the recycle treatment unit for use in identifying part names and numbers. This proved useful when communicating with manufacturers' representatives during troubleshooting. However, the combination of training provided and the manual supplied were judged inadequate by the mechanics on several troubleshooting occasions.

Descriptions of the required preventative maintenance checks and services (PMCS) were located throughout the manual as opposed to consolidated into a checklist form. This required the operator to page through the manual to determine PMCS requirements. The operators developed their own checksheet, which was derived from the manual. It is recommended that Landa develop and provide such a checksheet to future customers.

The manual also was ambiguous on what event triggered a service. For example, it was not specified what time period or what head loss across the multimedia filter should necessitate a backflush event. The manufacturer's representative explained that the cause of the ambiguity was the variety of applications that the recycle treatment unit was being used for.

Personal protective equipment such as gloves and eye protection are required for maintenance actions involving handling the liquid sodium hypochlorite (10% solution, CAS# 7681-52-9), aluminum sulfate (48-52%, CAS# 10043-01-3), buffer solutions, and muriatic acid. Complete safety procedures for handling these chemicals were not outlined in the user manual. Generally the manual does not appear adequate to support maintenance by shop personnel.

Maintainability issues also pertain to premature structural failures. Several valves became difficult to operate, and a clean filter alarm functioned improperly by sounding during the backwash of the multimedia filter.

The cleaning of the ORP and pH sensors posed a significant safety problem, which resulted in an injury to an operator. The sensors are located within the CLP approximately 9 ft off the ground. The recycle treatment platform does not include an access mechanism. The recycle treatment unit's platform prevents the positioning of a ladder close enough to the unit. The cleaning/calibrating of the sensors involves the use of hydrochloric acid. The hazard was categorized as an IIB (Reasonably Probable to occur with severe injury or severe system damage) in accordance with ATC Test Operating Procedure 1-1-012. A problem with a code IIB safety designation is a system deficiency. A later version of this Landa system is said to have a built-in ladder to access the CLP.

### *Maintainability – RGF*

The operational and maintenance manual provided an adequate description of the theory of operation and descriptions of the treatment processes. It also provided a chapter describing a preventative maintenance schedule. The manual did not provide adequate illustrations of the system components nor adequately number parts. The manual was judged in general by the mechanic as an inadequate aid for troubleshooting.

Maintainability issues include the requirement for tools not typically used at an Army organizational maintenance shop, for example, a bottlebrush to clean the Catalytic Chamber. Maintenance actions involving handling 35 percent hydrogen peroxide require the use of personal protective equipment such as gloves and eye protection. Several of the PVC valves became difficult to open over time.

### *Reliability*

Reliability is defined here as average time between operational failures or unscheduled maintenance of the systems. An operational failure occurred if: (1) washing could not continue without damage to the treatment system or the washer, (2) there would be an unplanned discharge of water due to a malfunction of the recycle system, or (3) the water supplied to the steam cleaner appeared dirty to the operator. An unscheduled maintenance action was defined as any maintenance action not required by a daily, weekly, or monthly PMCS.

### Landa.

During the test of the Landa system, 13 operational failures occurred and an additional 19 unscheduled maintenance actions occurred. An operational failure occurred for every 19.6 hours of operation. For every 100 hours of washing, there were 5.5 operational failures and 15.3 unscheduled maintenance actions.

Ten of the 13 operational mission failures documented were related to the control of water within the washrack system. The automatic addition of unneeded make-up water caused a need to discharge the excess water. The relatively small storage tank contributes to the excess water problems. The tank stores 65 gal of recycled water, which can supply the steamer for approximately 14 minutes. However, the wash process, the sedimentation basin, and the use of a valve to constrict influent flow from the sump pump (four incidents of Valve-1 restrictions were recorded), often delay the washwater flow for more than 14 minutes before it returns to the recycle system. When this occurs, washing has emptied the 65-gal tank, the low-water sensor shuts off flow to the steam cleaner and opens the make-up water valve to fill the tank, and use of the washrack is interrupted. When the washwater does return to the treatment system, the system recognizes an excess water situation. Depending on the system control settings, the excess water is either automatically discharged or returned to the washrack drain to be continually recycled or manually removed.

There were 107 incidents when the 65-gal storage tank became empty during wash events, and washing was temporarily stopped. Most incidents did not become operational failures, nor were they counted as unscheduled maintenance. The incompatibility of the recycle system with the wash process was considered a design issue and was counted as one operational failure.

Three of the operational failures were attributed to poor water quality being delivered to the steam cleaner. Filter pressure gauge readings did not indicate filter maintenance was required. The operational failures were clustered in the final month of the demonstration. The backwashing of the multi-media filter and cleaning of the cartridge filters provided a temporary partial improvement of the water quality. The increased frequency of backwashing appears to indicate that a purge of the water and sediments in the washrack system was required. The frequency of the washrack clean out task would appear to be quarterly.

Other maintenance actions that were considered to be unscheduled were generally attributable to plumbing leaks (chemicals and water) and gauge or control type problems. The inlet flow meter became non-functional at a rate at which cleaning became a part of the daily checks and service. The cleaning/repair of the flow meters (inlet or filter) was documented eight times prior to incorporating its cleaning into the daily inspections. These eight actions were recorded as unscheduled maintenance actions. After the cleaning was incorporated into the daily PMCS, each cleaning time was recorded as scheduled maintenance. The inlet flow gauge was used during PMCS to determine the delivery rate of water from the sump to the recycle treatment unit. Solids in the water from the sump resulted in the clogging of the gauge. The cleaning of the gauge is an easy task requiring only a screwdriver and a cotton-tipped applicator. The inlet flow meter used is an inadequate tool to gauge the flow rate to the recycle treatment unit due to the frequency of cleaning tasks required.

On four occasions, chemical leaks occurred that required the use of personal protective equipment. Three of these leaks involved sodium hypochlorite (10 percent solution, CAS Number 7681-52-9) leaking from the sanitizer pump's outlet piping. The corrections involved the operator tightening the clamp or trimming the supply. The fourth leak involved liquid alum (48 to 52 percent aluminum sulfate, CAS Number 10043-01-3) from the pH pump outlet tube.

### RGF

During the RGF test, seven operational failures occurred. Four of the operational failures were attributable to the poor manufacturing of the Series I Tank. The drain holes from the Inclined Tube Compartment, the HCA-2 Compartment, and the Multi-Media Compartment were cut out too large in the Series I Tank, which caused the Adapt-A-Flex bushings to pull-out during maintenance activities. Initially the manufacturer attributed the pull out of the drain lines to overzealous mechanics, but eventually recognized the manufacturing defect and installed a new Series I Tank under warranty and at no cost to the Government.

Two mission failures occurred as a result of excess water being added to the system. The first occurrence was attributed to duration and frequency of automated filter back-washing, a process that uses municipal water. The second occurrence happened when a blockage of the drainage header precluded overflow from the Series I tank to the washbay. An attempt to determine whether the system would operate in a closed loop mode was made toward the end of the demonstration by opening the manual make-up water valve. Make-up water began filling the washrack system and continued to a point where treated water was discharged to the sanitary sewer line. Excess water that accumulated was attributed to the improper positioning of the FW-2 valve. Mechanics' attempts to troubleshoot the excess water problem using the operation and maintenance manual were unsuccessful. Because of the mechanic's choice to operate the system in a manual make-up water mode and the unsuccessful troubleshooting, it is unclear whether the system would work in a closed loop mode.

The last mission failure involved the automatic addition of hydrogen peroxide at too great a rate. The elevated peroxide concentration created eye and skin irritation to the operator during a steam cleaning event. The failure was attributed to the improper positioning of the peroxide feed tube within the 55-gallon drum. The feed hose was pushed to the bottom of the drum through a hole drilled in the drum's small cap and sealed to prevent release of peroxide vapors into the washbay. The positioning of the tube resulted in a kinking of the supply hose. When the peroxide feed rate could not be raised sufficiently the mechanic repositioned the supply hose which resulted in an excessive feed rate. This failure was not included in the mean time between hardware mission failures calculations presented in Table 7.

Three additional unscheduled maintenance actions occurred, two of which involved plumbing leaks. The third maintenance action resulted when the lifting straps on the HCA-2 Hydrocarbon Absorber Filter broke.

An operational failure of the RGF system occurred for every 42 hours of washing operation. For every 100 hours of washing there were 2.4 operational mission failures and 3.6 unscheduled maintenance actions.

Hardware mission failures (HMF) are a subset of operational mission failures (OMF). The HMF subset only includes OMFs attributed to the washrack recycle treatment systems, and do not include failures of government furnished equipment or operator error. Mean Time Between Hardware Mission Failures (MTBHMFs) is calculated by dividing the operating hours by the number of hardware mission failures. The point estimate and lower 80-percent confidence limit on MTBHMF were calculated for each system. The results are presented in Table 7. The point estimate is the (total test time)/(the number of failures). The lower 80 percent confidence limit is the value for which the true mean time between failure should fall with an 80 percent degree of confidence.

Mean Time To Repair (MTTR) is the average maintenance time required to correct unscheduled problems and does not include any daily services or time interval services. For the recycle treatment system, the average maintenance time required to correct unscheduled maintenance problems was 0.46 and 1.46 for Landa and RGF, respectively.

Table 7. Mean time between hardware mission failures (MTBHMF) for WRTS system.

| | | MTBHMF (Recycle Treatment System) | | |
|---|---|---|---|---|
| Item ID | RAM Hrs | No. of Failures | Point Estimate | Lower 80% Conf. Limit |
| Landa | 254.3 | 13 | 19.6 | 15.0 |
| RGF | 252.2 | 6 | 42.0 | 27.8 |

Table 8. Maintenance evaluation — recycle treatment system.

| Parameter | Landa | RGF |
|---|---|---|
| Mean Time To Repair (MTTR) Point Estimate | 0.46 | 1.46 |
| Maintenance Ratio (MR) Point Estimate | 0.23 | 0.19 |

Maintenance Ratio (MR) refers to the "x" number hours of maintenance (scheduled and unscheduled included) the system requires for every hour of operating time. The Landa system required 0.23 man-hour of maintenance for every operating hour. The RGF system required 0.19 man-hour of maintenance for every operating hour. Table 8 shows results of the maintainability evaluation.

The scope of the reliability and maintainability portion of the demonstration was severely constrained due to resource limitations. The short duration of the test precluded either system from moving to the useful life stage of system reliability (reference Kapur, Lamberson, Reliability in Engineering Design, 1977 John Wiley and Sons). Both systems suffered from infant mortality type failures created by system integration problems or manufacturing defects. Had the useful life stage been reached, the reliability numbers would likely have improved as system integration and manufacturing defects were corrected. If, for instance, the 10 mission failures caused by water management were reduced to one failure, a MTBHMF of 63.6 would have been achieved. If the four mission failures attributed to RGF manufacturing defects were reduced to one failure, a MTBHMF of 84.1 would have been achieved. The life expectancies of the wastewater treatment systems as well as their sub-components greatly exceed the demonstration period. For example, the Landa system manufacturer claims a typical life for the pH sensor to be 1 to 2 years. The short test duration precluded the determination of system or component life expectancies. Extending the duration of the demonstration period coupled with collecting maintenance data (including number of hours operated for each failure) at other sites would have greatly enhanced the reliability data.

## Treatment Performance

The water quality data accumulated for both system tests is included in Appendix B. Samples were taken from two locations in the systems: the treated water storage tank, and the nozzle of the pressure washer. The purpose of measuring water quality was to see if certain contaminants such as COD (chemical oxygen demand), TSS (total suspended solids), TPH and PAH (petroleum and aromatic hydrocarbons), TDS (total dissolved solids), alkalinity, hardness, and dissolved metals would accumulate in the recycle water. The brief duration of each system test makes it difficult to identify long-term trends in water quality. And the large amount of make-up water added to the Landa system certainly must have affected the water quality in the recycle system, unfortunately sampling was not frequent enough to quantify the dilution effect.

A general discussion of the data from each of the tested systems follows. Appendix B, Water Analysis Data, contains the results of the recycle water sample analysis.

### *Landa Recycle Water Quality*

- COD fluctuated above 1600 mg/L in November 1996 and increased again in January 1997. This is most likely due to unusually large slugs of contaminants (oil, antifreeze, etc.) coming from the washing process. It seemed to take several weeks for the COD causing substances to be removed (or diluted). COD seemed to remain above 300 mg/L at the end of the test.

- Suspended solids remained exceptionally low throughout the test. Four samples were above 2 mg/L, with the high being 33 mg/L.

- Dissolved solids did seem to increase with time, going up to above 1500 mg/L at the end of the test. Dissolved solids in the tap water were 110 mg/L.

- TPH, an indicator of oil and grease, remained undetectable until the end of the test period. Visual observations confirm that the majority of free oil in the washwater was removed in the drain pan.

- PAH was always below detection limits.

- Only four ethylene glycol analyses were done. The 25 January sample had 500 mg/L, indicating some antifreeze had been washed into the system. That slug of glycol would have contributed to the high COD concentrations read on 21 and 27 January. The system is not designed to remove ethylene glycol.

Operators should prevent slugs of material such as glycol from entering the recycle system by using absorbents, containment pans, or other means.

- Hardness, after a 1-month period of increasing concentration, seemed to level at values between 150 mg/L and 200 mg/L (as $CaCO_3$).

- The alkalinity remained below 50 mg/L (as $CaCO_3$) throughout the test, but rose inexplicably to 177 mg/L in the last sample taken. The pH was always slightly acidic, with one reading at 5.7 and the rest between 6.2 and 6.8.

- There was no significant accumulation of metals in the recycle water, though cadmium and zinc were detected at levels above the levels in tap water. No metal concentration exceeded the Aberdeen Proving Ground limits for discharge to the sanitary sewer.

- Exceptionally high levels of coliform bacteria were detected in the recycle water. One sample had a count exceeding 160,000 organisms/100 ml. It was determined that the high coliform counts were probably due to operation error. The test strips provided to measure chlorine residual showed that the chlorine concentration was seldom high enough to provide adequate disinfection. However adequate adjustments were not made to increase the sodium hypochlorite feed rate to provide an acceptable level of chlorination.

### *RGF Recycle Water Quality*

- COD levels seemed to fluctuate between 90 and 300 mg/L.

- Suspended solids remained very low, rising above 20 mg/L only once to a high of 118 mg/L.

- Dissolved solids concentration generally rose during the test, peaking at 618 mg/L and 564 mg/L in September. All other samples were less than 388 mg/L.

- Nine of the 12 TPH values were less than 10 mg/L. The 2263 value occurred because there was a spill of diesel fuel on the washrack that day. Apparently, a significant amount of diesel fuel passed through the treatment system to the storage tank, causing the washwater to be very oily. Operators should prevent slugs of contaminants, such as diesel fuel, from entering the recycle system by using absorbents, containment pans, or other means.

- All PAH measurements were below analytical detection limits.

- All three ethylene glycol analyses were below the analytical detection limit.

- Hardness increased somewhat from 63 mg/L to a fairly stable level at less than 120 mg/L (as $CaCO_3$).
- Alkalinity peaked at 193 mg/L, but otherwise did not exceed 167 mg/L. The pH ranged from 6.3 to 7.3.
- Of the heavy metals tested, only copper and zinc were measured at above detection levels, and those concentrations were well below the APG limits for discharge to the sanitary sewer.
- Control of coliform bacteria was also a problem in the RGF test. Coliform counts rose to a high of 9000 organisms/100 ml in the last month of the test. The likely cause of the elevated coliform counts is attributed to operator error. The operators failed to adequately adjust the peroxide feed to maintain the concentration required for proper disinfection. A temporary kink in the peroxide feed line also contributed to inadequate disinfection. The kink was not apparent to the mechanics as it was located at the bottom of the 55-gal hydrogen peroxide storage drum.

### *Significant Observations*

- The contaminants that were expected to accumulate did accumulate, but not always in a linear manner. Frequent discharges from the systems and additions of make-up water undoubtedly caused disruptions to the expected accumulation of dissolved material, and affected the measurements of dissolved solids, hardness, and alkalinity. Eventually water must be replaced in any closed-loop recycle treatment system. The washwater at the test site for this study would probably be replaced every 6 months.
- COD levels were higher than might be acceptable, and are probably caused by dissolved organics. These organics may have provided nutrients for bacterial growth and contributed to the high coliform levels. Additional activated carbon filtration, or other means to remove organics, is recommended for Army recycle systems.
- Operators should be cautioned to prevent slugs of contaminants, such as fuel or antifreeze, from entering the recycle systems from the washrack. Spill control materials should be readily available to the operators.
- The disinfection systems of both systems were not operated properly, resulting in large populations of bacteria in the recycle water. No operational failures or unscheduled maintenance actions occurred because of the bacteria, though a buildup of bio-mass might have caused operational

problems after a longer evaluation period. The value of disinfection is not obvious to the average operator, and should be emphasized during operator training.

# 5 Conclusions and Recommendations

## Conclusions

1. It takes a relatively long time for washwater to flow through the washrack and pretreatment, and back to the recycle treatment system. For the system to function efficiently, the storage tank must contain enough water to compensate for the delay. The 65-gal water storage tank in the Landa system was too small to make such compensation. The 500-gal storage in the RGF system was certainly adequate, and possibly could have been smaller for this application.

2. Scheduled maintenance for each system took about 25 minutes per workday. Specific personnel were assigned to perform these tasks.

3. Much of the initial operator training was not comprehended, due to unfamiliarity with the equipment.

4. It was necessary to have a person readily available (in this case, on the installation) who was familiar with the design and operation of the system to determine when malfunctions required a service call by an authorized service representative.

5. Neither system operated in complete recycle mode, and discharges from both systems occurred. Storage tanks, and ultimately a sewer connection, were installed at the test site for disposal of the discharges.

6. The disinfection systems of both systems were not operated properly, resulting in large populations of bacteria in the recycle water. The value of disinfection is not obvious to the average operator, and should be emphasized during operator training.

7. Slugs of organic material, such as antifreeze or fuel, easily find their way into washrack recycle water. These organics provide unwanted nutrients that will support biological growth in the systems. Most recycle systems, including the two tested, are not designed to remove organics such as ethylene glycol.

8. Both systems tested required a significant amount of unscheduled maintenance causing down time. For both systems, for every 100 hours of washing, the system went down about 5 times. Any facility purchasing a recycle system should be prepared for downtime, and have resources available for repairs. Downtime can be as short as a few hours, but extend to several days if a work order or service call is necessary.

9. Improvements to the Building 338 washrack were not planned according to guidance presented in the USAEC technical report, *A Decision Tree for Improving Washrack Oil/Water Separator Operations*. Had this guidance been available and followed, a recycle treatment system would not have been purchased.

## Recommendations

1. Any recycle system at an Army washrack should have a storage tank that holds enough treated water for at least 1 hour of washing at peak flow. Storage tank volume = (60 minutes) x (gal/min. flow from wash hoses).

2. Assign 2 or 3 persons to perform scheduled maintenance on recycle systems to prevent constant retraining, and to avoid downtime caused by lack of familiarity with the system. These tasks will become part of these workers' normal routine because recycle systems normally require maintenance whether they are used or not.

3. A second training session occurring 3 to 6 months after initial start-up training should be provided to the recycle system operators. At that time the operating personnel will have gained enough on-the-job experience to benefit from the additional session.

4. Assign someone who has formal training with water or wastewater treatment systems (i.e., an environmental engineer or treatment plant operator) to provide in-house technical support to a washrack with a recycle system.

5. Provide for legal disposal of scheduled and unscheduled wastewater discharges from the recycle system. That provision must be one of the following: a connection to sanitary sewer, a tank for temporary storage prior to transfer to a treatment facility, or a permit to discharge wastewater to the environment.

6. Provide for the characterization and legal disposal of wastes such as contaminated carbon, multimedia, cartridge filters and solids.

7. Care should be taken to operate the disinfection systems according to operation manuals in order to control microorganisms, including periodic checks for disinfectant residual using test strips. Metering of chemicals, including ozonation, should also be linked to periodic analysis for indicator organisms, such as coliform bacteria. Daily maintenance should include a visual inspection for biological growth.

8. Operators should be encouraged to prevent slugs of organic contaminants from entering any recycle system. Spill control materials should be available to the operators.

9. A facility acquiring a recycle system should have resources available for at least five repairs for every 100 hours of use.

10. A facility considering the purchase of a recycle treatment for a washrack should evaluate other alternatives first, as per the guidance in USAEC report SFIM-AEC-ET-R-98003, *A Decision Tree For Improving Washrack Oil / Water Separator Operations.*

# References

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USACERL Test Plan to Evaluate RGF and Landa Treatment Systems (25 March 1996).

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USAEC/USACERL, Statement of Work, Project Title: *Evaluation of Washrack Treatment Systems* (March 1996).

USAMDW, *Research/Development Proposal* (5 October 1995).

USAATC Test Operating Procedure 1-1-012.

# Appendix A: Test Incident Report Summary

| Tir# | Date | Incident Description | Work hours |
|---|---|---|---|
| LANDA | | | |
| K2-A000003 | 961009 | Cartridge filter canister leaking at drain outlet from connection between cartridge filter drain bushing and 90 degree elbow. | 0.05 |
| K2-A000005 | 961009 | Liquid alum leaking from flexible hose connection to the pH pump exit; Tightened clamp. | 0.08 |
| K2-A000006 | 961009 | Liquid sodium hypochlorite leaking from flexible tubing on exit side of sanitizer pump; Tightened clamp. | 0.08 |
| K2-A000009 | 961015 | The closed loop washrack overflowed to the environment; Adjusted Valves 1 and 11. | 4.67 |
| K2-A000010 | 961104 | Water flow from the sump to the CLP was not registering on the flowmeter; Removed dirt debris through pipe, Adjusted Valve 1. | 0.10 |
| K2-A000011 | 961104 | Pressure gauge on Cartridge Filter is inoperative; Replaced damaged gauge. | 0.23 |
| K2-A000012 | 961104 | Water supply interupted during steam cleaning; Problem could not be replicated. | 1.05 |
| K2-A000013 | 961106 | Oil/ water mixture is splashing out of oil collection tank; Adjusted Oil Skimmer Funnel to reduce flow rate of liquid into the funnel. | 0.20 |
| K2-A000016 | 961107 | Clean Filter alarm sounds during Multi-Media filter backwash after depressing the float override switch. | 0.03 |
| K2-A000017 | 961108 | The out of range light on the Water Maze 210 Control Unit illuminated while in pH mode; Increased feed rate of chemical feed pump for Liquid Alum and sodium hypochlorite. | 0.33 |
| K2-A000018 | 961108 | Sodium Hypochlorite leaking from the injection port on the CLP; Removed flexible tubing and trimmed end of hose. | 0.20 |
| K2-A000025 | 961122 | The steam cleaner failed to ignite in burner mode; After a short time the steam cleaner ignited with heavy smoke. | 0.13 |
| K2-A000029 | 961125 | The filter timer was out sequence with current time; Reset timer. | 0.07 |
| K2-A000030 | 961125 | Make-up water was added to the system during filter mode operation. | 0.00 |
| K2-A000031 | 961125 | The filter flowmeter was inoperative; Bled air from gauge by loosening pipe plug. | 0.07 |
| K2-A000032 | 961125 | A blockage in Valve 1 caused a near overflow to the environment; Adjusted flow to 14 gal per minute. | 0.10 |
| K2-A000038 | 961202 | The inlet flowmeter gauge was inoperative; Cleaned meter housing and float. | 0.13 |
| K2-A000040 | 961202 | Safety hazard when cleaning ORP/pH Sensors located within the CLP tank due to lack of an access mechanism. | 0.18 |
| K2-A000041 | 961203 | The Recycle Teatment Unit and the Cleaning unit are incompatible. | 0.03 |
| K2-A000045 | 961226 | The water flow into the CLP was restricted severely at Valve 1; Opened Valve 1 fully to clear blockage. | 0.15 |
| K2-A000048 | 970106 | The flow meter indicated no flow as the sump pump delivered water; Cleaned meter. | 0.10 |
| K2-A000050 | 970110 | Discoloration of water indicating oil layer not being skimmed from top of CLP properly; Adjusted flow. | 0.05 |
| K2-A000052 | 970116 | During operations, water was observed to be backing up into the sump pit. | 0.10 |
| K2-A000053 | 970116 | The Inlet Flowmeter was inoperative; Cleaned tube. | 0.23 |
| K2-A000054 | 970116 | The plastic coating on the float was cracked; Cleaned float. | 0.03 |
| K2-A000055 | 970117 | The Inlet Flowmeter did not register flow as the sump pump operated; Cleaned flowmeter and bled air from meter. | 0.27 |

| Tir# | Date | Incident Description | Work hours |
|---|---|---|---|
| K2-A000056 | 970122 | The Inlet Flowmeter was inoperative; Cleaned meter, bled air from tube. | 0.33 |
| K2-A000057 | 970122 | A leak was noted at the threaded connection between the CLP and Valve 14 piping; Maintenance deferred. | 0.02 |
| K2-A000058 | 970123 | The solids and washwater were removed from the washbay pan. | 0.00 |
| K2-A000059 | 970125 | Water overflowing from 600 gal storage tank, no flow at inlet flowmeter; Cleaned Flowmeter and adjusted Valve 1. | 3.00 |
| K2-A000060 | 970201 | Excess make-up water in closed loop system; Cleaned inlet flowmeter. | 1.25 |
| K2-A000061 | 970205 | The reconfiguration of the float controls increase the potential for freezing. | 0.00 |
| K2-A000064 | 970210 | Sodium Hypochlorite leaked from the injection port on the CLP; Trim Flexible tubing at injection port. | 0.23 |
| K2-A000067 | 970301 | Poor water quality and a film on the wash item; Backflushed Multi-Media filter, cleaned Cartridge filters, inlet screen, Tank2 and Auxillary Tank. | 1.42 |
| K2-A000069 | 970318 | The water in Tank 2 appeared light brown; Backwashed Multi-Media fileter and cleaned canister filters. | 0.87 |
| K2-A000074 | 970321 | The operator stopped washing because dirty water was coming from the wand; Replaced cartridge filters. | 1.30 |
| K2-A000075 | 970321 | The mechanic noticed the water was about to overflow the sump; Opened Valve 1. | 0.75 |
| K2-A000078 | 970324 | The sump pit water level was within an inch and a half of overflowing. | 0.10 |
| K2-A000079 | 970325 | Excess make-up water to within 2 inches of overflowing; Opened Valve 1, adjusted skimmer to reduce flow of water. | 0.48 |
| **RGF** | | | |
| K2-A000082 | 970619 | Two straps were broken on an HCA-2 Hydrocarbon Absorber Filter; repaired straps with tape. | 0.03 |
| K2-A000083 | 970623 | The sump pump failed to operate with water level well above the pump activation point; Replaced sump pump. | 4.00 |
| K2-A000084 | 970710 | The duration of backflushing was reduced to eliminate the addition of excess. | 1.70 |
| K2-A000085 | 970711 | Pipe holding the SID-1 pulled out from the Series I Tank; Repaired. | 2.07 |
| K2-A000087 | 970807 | Adapt-A-Flex Pipe Tank Bushing pulled out at position SID-3; Repaired. | 1.25 |
| K2-A000088 | 970807 | Adapt-A-Flex Pipe Tank Bushing pulled out of the Series I Tank; Additional action required. | 6.00 |
| K2-A000089 | 970915 | Approximately 303 gal of water Leaked At SID-3 Grommet - Temporary Repair. | 1.25 |
| K2-A000090 | 971009 | Replaced Series I Tank under warranty due to deficiencies resulting in incorrent sized SID holes. | 8.75 |
| K2-A000091 | 971020 | Hose connected from UV/03 Chamber/CFC-1 to CA-1/HCA-3 was disconnected causing leak; Installed new hose. | 0.20 |
| K2-A000095 | 971113 | System Overflow From Series III Tank, water in Series I Tank would not drain through SID Valves; Shortened discharge pipe. | 0.13 |
| K2-A000096 | 971113 | Peroxide Level in Series III Tank exceeded 100 parts per million; Flushed entire system and added new water. | 0.33 |
| K2-A000097 | 971115 | PVC Pipes on both ends of CFC Pump Leaking; Installed new connections and PVC Pipes. | 0.50 |

# Appendix B: Water Analysis Data

Table B1. General chemical analysis data, RGF treatment system.

| Date | Source | Temp °C | pH | DO (mg DO/L) | COD (mg O2/L) | TSS (ppm) | TDS (ppm) | Total Coliform /E. coli (MPN/100mL) | Total Chlorine (ppm) | Free Chlorine (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 14-Jul-97 | Stored | 27.7 | 7.02 | 3.64 | 29.3 | 3.0 | 137.0 | 170 | 0.08 | 0.04 |
| 21-Jul-97 | Stored | 25.2 | 6.98 | 4.34 | 36.7 | 4.0 | 216.0 | 7 | 0.07 | 0.04 |
| 28-Jul-97 | Stored | 29.1 | 6.60 | 3.64 | 108.7 | 6.6 | 231.7 | >1600 | 0.02 | 0.04 |
| 4-Aug-97 | Stored | 27.5 | 6.62 | 2.80 | 297.5 | Too Oily | Too Oily | >1600 | 0.25** | 0.28** |
| 18-Aug-97 | Stored | 26.5 | 6.70 | 4.11 | 91.6 | 0.0 | 248.0 | 200 | | |
| 25-Aug-97 | Stored | 25.6 | 6.30 | 4.16 | 94.5 | 20.0 | 252.0 | 200 | | |
| 2-Sep-97 | Stored | 26.4 | 6.91 | 2.92 | 138.5 | 0.0 | 360.0 | 800 | 0.06 | 0.04 |
| 8-Sep-97 | Stored | 23.4 | 7.02 | 3.61 | 160.0 | 0 | 564.0 | 40^ | | |
| 16-Sep-97 | Stored | 24.0 | 7.31 | 4.09 | 113 | 11.8 | 317.6 | 5,000 | 0.02 | 0.01 |
| 22-Sep-97 | Stored^ | 24.0 | 7.05 | NT | 215.0 | 118.2 | 618.2 | 9,000 | NT | NT |
| 29-Sep-97 | Stored | 24.0 | 7.08 | NT | 226.0 | 4.0 | 388.0 | 7,000 | NT | NT |
| 6-Oct-97 | Stored | 24.0 | 7.10 | NT | 246.7 | 0.0 | 373.0 | 3,000 | NT | NT |

* See separate page for this data.
** Sample contaminated with fuel oil.
NT Not Tested
^ pH and temperature of samples taken in lab. Tank low. Coliform taken from sample jar.

Table B2. TPH data, RGF treatment system.

| Date | Source | TPH (ppm) |
|---|---|---|
| 14-Jul-97 | Stored | 0.6 |
| 21-Jul-97 | Stored | <0.5 |
| 28-Jul-97 | Stored | 1.4 |
| 4-Aug-97 | Stored | 2,263 |
| 18-Aug-97 | Stored | 8.4 |
| 24-Aug-97 | Stored | 7.1 |
| 2-Sep-97 | Stored | 2.8 |
| 8-Sep-97 | Stored | 1.9 |
| 16-Sep-97 | Stored | 84.7 |
| 22-Sep-97 | Stored | 21.6 |
| 29-Sep-97 | Stored | 5.8 |
| 6-Oct-97 | Stored | <1.0 |

Table B3. PAH data, RGF treatment system.

| Date | 14-Jul-97 | 8-Sep-97 | 6-Oct-97 |
|---|---|---|---|
| Source | Stored | Stored | Stored |
| Naphthalene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Acenaphthylene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Acenaphthane | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Fluorene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Phenanthrene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Anthracene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Fluoranthene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Pyrene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Benzo(a)anthracene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Chrysene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Benzo(b)fluoranthene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Benzo(k)fluoranthene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Benzo(a)pyrene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Dibenzo(a,h)anthracene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Indeno(1,2,3-cd)pyrene | <0.5 ppb | <0.5 ppb | <0.5 ppb |
| Benzo(ghi)perylene | <0.5 ppb | <0.5 ppb | <0.5 ppb |

Table B4. Metals analysis, RGF treatment system.

| Date | Source | Copper (Cu) | Cadmium (Cd) | Lead (Pb) | Nickel (Ni) | Chromium (Cr) | Zinc (Zn) | Silver (Ag) |
|---|---|---|---|---|---|---|---|---|
| 14-Jul-97 | Stored | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | 0.17 | <0.10 |
| 21-Jul-97 | Stored | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | 0.13 | <0.10 |
| 8-Sep-97 | Stored | 0.19 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| 6-Oct-97 | Stored | <0.01 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |

Table B5. Ethylene glycol data, RGF treatment system.

| Date | Source | Ethylene Glycol |
|---|---|---|
| 14-Jul-97 | Stored | <1.0 ppm |
| 8-Sep-97 | Stored | <1.0 ppm |
| 6-Oct-97 | Stored | <1.0 ppm |

**Table B6. Alkalinity data, RGF treatment system.**

| Date | Source | Total Alkalinity mg/l CaCO3 | pH |
|---|---|---|---|
| 14-Jul-97 | Stored | 42 | 7.00 |
| 21-Jul-97 | Stored | 51 | 7.09 |
| 28-Jul-97 | Stored | 72 | 6.90 |
| 4-Aug-97 | Stored | 116 | 6.88 |
| 18-Aug-97 | Stored | 66 | 6.57 |
| 25-Aug-97 | Stored | 73 | 6.80 |
| 2-Sep-97 | Stored | 155 | 7.65 |
| 8-Sep-97 | Stored | 193 | 7.29 |
| 16-Sep-97 | Stored | 110 | 7.13 |
| 22-Sep-97 | Stored | 167 | 7.22 |
| 29-Sep-97 | Stored | 158 | 6.90 |
| 6-Oct-97 | Stored | 154 | 7.3 |

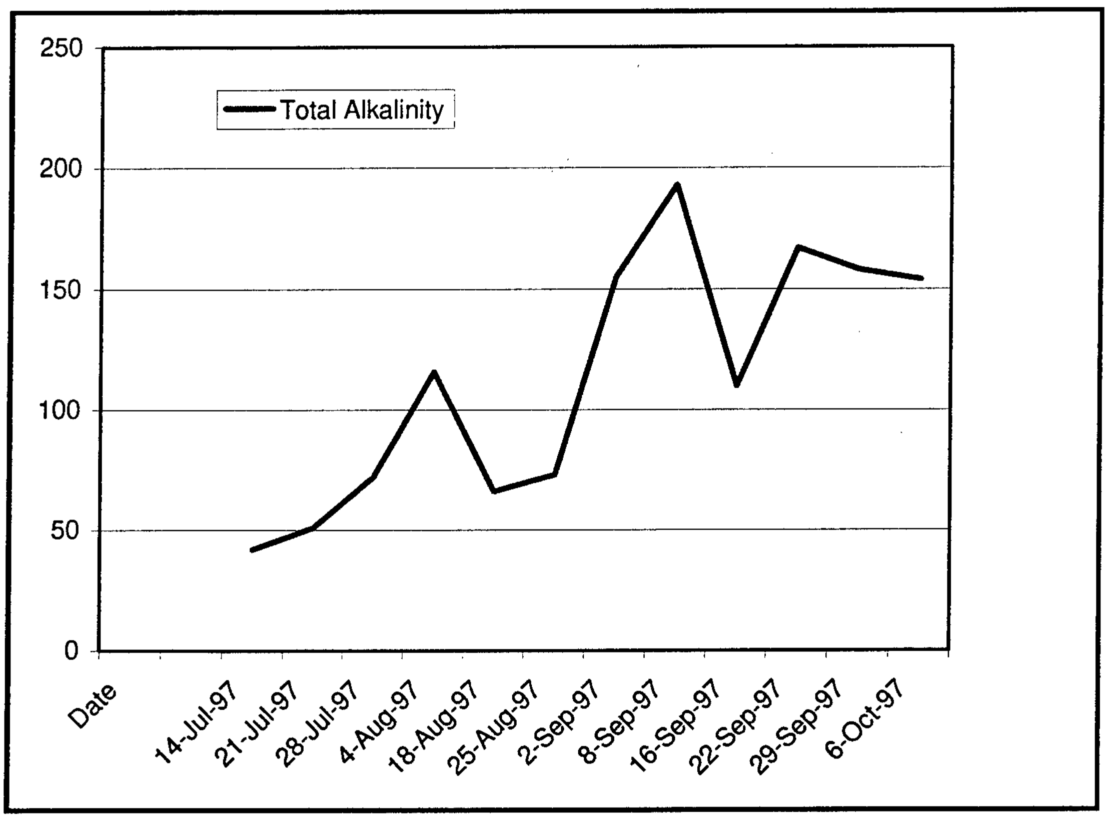


**Figure B1. Alkalinity data, RGF treatment system (corresponds to data listed in Table B5).**

Table B7. Hardness data, RGF treatment system.

| Sample Date | Sample Source | Hardness mg/L $CaCO_3$ | Calcium mg/L | Magnesium mg/L |
|---|---|---|---|---|
| 14-Jul-97 | Stored | 63.2 | 14.70 | 6.40 |
| 21-Jul-97 | Stored | 64.0 | 18.22 | 4.49 |
| 28-Jul-97 | Stored | 102.0 | 29.37 | 6.97 |
| 4-Aug-97 | Stored | 165.0 | 46.05 | 12.22 |
| 18-Aug-97 | Stored | 72.0 | 21.57 | 4.48 |
| 25-Aug-97 | Stored | 83.0 | 25.23 | 4.86 |
| 2-Sep-97 | Stored | 112.0 | 35.24 | 5.83 |
| 8-Sep-97 | Stored | 98.0 | 7.93 | 4.81 |
| 16-Sep-97 | Stored | 90.3 | 27.1 | 5.51 |
| 22-Sep-97 | Stored | 116.9 | 37.6 | 5.90 |
| 29-Sep-97 | Stored | 106.2 | 33.4 | 5.54 |
| 6-Oct-97 | Stored | 116.4 | 34.3 | 7.45 |

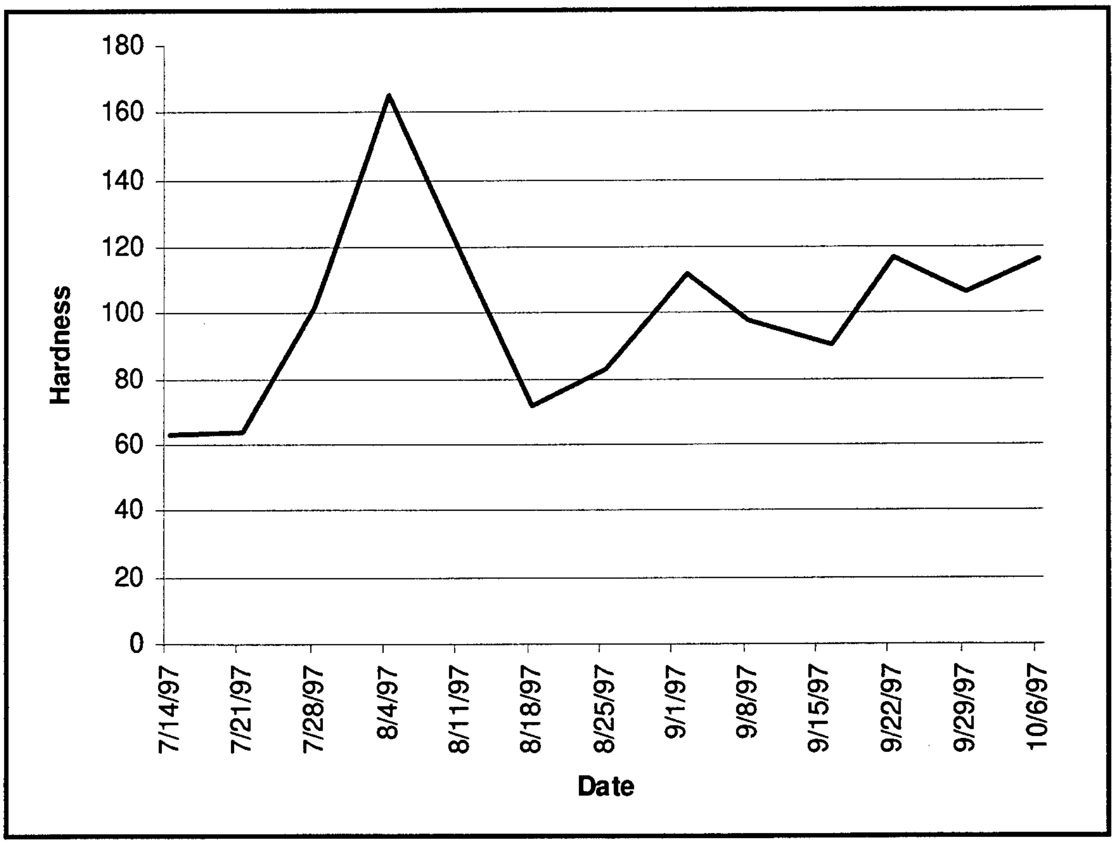


Figure B2. Hardness vs. Time, RGF treatment system (corresponds to data listed in Table B6).

Table B8. General chemical analysis data, LANDA treatment system.

| Date | Washrack Hours | Source | Temp °C/°F | pH | DO (mg DO/L) | COD (mg $O_2$/L) | TSS (ppm) | TDS (ppm) | Total Coliform /E. coli (MPN/100mL) | Total Chlorine (ppm) | Free Chlorine (ppm) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4-Nov-96 | 749.8 | Stored | 15.1/59.2 | 7.40 | 4.60 | 0.66 | 2.0 | 136.0 | <2.2/+ | NT | NT | Clear |
| 12-Nov-96 | 936.8 | Stored | 13.3/55.9 | 6.47 | 4.14 | 0.33 | 0.0 | 172.0 | <2.2/+ | NT | NT | Clear |
| 18-Nov-96 | 1,084.1 | Stored | 19.5/67.1 | 6.17 | 3.22 | 1650.0 | 32.8 | 145.9 | NT | <1.0 | <1.0 | Clear |
| 25-Nov-96 | 1,248.6 | Stored | 15.1/59.2 | 6.16 | 3.37 | 374.8 | 0.0 | 277.2 | 2.0/+ | 0.00 | 0.00 | Clear |
| 2-Dec-96 | 1,415.4 | Stored | 18.0/64.4 | 4.04 | 6.15 | 100.3 | 0.0 | 241.0 | 7.0/+ | 0.15 | 0.00 | Clear |
| 9-Dec-96 | 1,583.0 | Stored | 13.7/56.7 | 6.15 | 3.02 | 74.2 | 0.0 | 338.0 | ≥1600/+ | 0.10 | 0.02 | Clear |
| 16-Dec-96 | 1,750.2 | Stored | 16.3/61.3 | 5.94 | 2.34 | 32.0 | 2.0 | 586.0 | ≥16,000/+ | 0.02 | 0.01 | Clear |
| 23-Dec-96 | 1,917.7 | Stored | 15.9/60.6 | 6.23 | 2.70 | 26.0 | 0.0 | 648 | >4000*/+ | 0.02 | 0.02 | Clear |
| 29-Dec-96 | 2,061.8 | Stored | 16.9/62.4 | 6.25 | 3.10 | 32.0 | 0.0 | 66.9 | 3400/+ | 0.02 | 0.01 | Clear |
| 6-Jan-97 | 2,253.1 | Stored | 16.6/61.9 | 6.32 | 2.68 | 31.3 | 2.0 | 589.0 | 50000/+ | 0.04 | 0.01 | Clear |
| 13-Jan-97 | 2,421.0 | Stored | 17.3/63.1 | 7.48 | 4.53 | 24.7 | 1.7 | 42.0 | 35,000/+ | 0.03 | 0.01 | Clear |
| 21-Jan-97 | 2,612.1 | Stored | 19.2/66.6 | 6.24 | 3.33 | 802.6 | 0.0 | 942.2 | ≥160,000/+ | 0.00 | 0.01 | Slightly cloudy |
| 27-Jan-97 | 2,755.9 | Stored | 17.7/63.9 | 6.05 | 2.30 | 752.7 | 14.0 | 651.0 | ***≥1,600/+ | 0.11 | 0.02 | Clear, slight organic smell |
| 26-Feb-97 | | Stored | 16.6/61.9 | 6.76 | 4.51 | 337 | 30 | 586.7 | 500/+ | 0.1 | 0.05 | Slightly cloudy |
| 25-Mar-97 | | Stored | 19.0/66.2 | 6.91 | 4.3 | 398 | 16 | 1556 | 17,000 | NT | 0 | Slightly cloudy |
| 25-Mar-97 | | Tank #1 | NT | NT | NT | NT | 133.3 | NT | NT | NT | NT | |
| 2-Oct-96 | | Tap Water | 23.5/74.3 | 7.60 | 6.29 | 4.33 | 0.0 | 110.0 | <2.2/+ | NT | NT | Clear |
| 4-Nov-96 | | Tap Water | 19.4/66.9 | 7.03 | 5.30 | NT | NT | NT | <2.2/+ | NT | NT | Clear |

NT = Not Tested
*Incubation period over 48 hrs which affected count.
**Too much oil in sample. Sample would not evaporate to dryness.
***Dilutions only to 1:100. All tubes were +. Value may be higher.
****Sample too oily for analysis.

Table B9. Ethylene glycol data, LANDA treatment system.

| Date | Source | Ethylene Glycol |
|---|---|---|
| 2-Dec-96 | Stored | 58 mg/l |
| 29-Dec-96 | Stored | <1.0 mg/l |
| 27-Jan-97 | Stored | 500 mg/l |
| 25-Mar-97 | Stored | 13 mg/l |

Table B10. TPH data, LANDA treatment system.

| Date | Source | TPH (ppm) |
|---|---|---|
| 18-Nov-96 | After Grate | 671 |
| 18-Nov-96 | Before Grate | 11,696 |
| 12-Nov-96 | Stored | <1.0 |
| 18-Nov-96 | Stored | <1.0 |
| 25-Nov-96 | Stored | <1.0 |
| 2-Dec-96 | Stored | <1.0 |
| 9-Dec-96 | Stored | <1.0 |
| 16-Dec-96 | Stored | <1.0 |
| 23-Dec-96 | Stored | <1.0 |
| 29-Dec-96 | Stored | <1.0 |
| 6-Jan-97 | Stored | <1.0 |
| 13-Jan-97 | Stored | <1.0 |
| 21-Jan-97 | Stored | <1.0 |
| 27-Jan-97 | Stored | 6.5 |
| 26-Feb-97 | Stored | 16.3 |
| 25-Mar-97 | Stored | 3.0 |
| 25-Mar-97 | Tank #1 | 46.2 |
| APGR 200-41 TPH, PPM | | 100 |

**Table B11. PAH data, LANDA treatment system.**

| Date | 4-Nov-96 | 2-Dec-96 | 29-Dec-96 | 27-Jan-97 | | |
|---|---|---|---|---|---|---|
| Source | Stored | Stored | Stored | Stored | | |
| Naphthalene | <1.0 *ppb | ND** | ND** | <2.0***ppb | 10 | <2.0 |
| Acenaphthylene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 2 | <0.5 |
| Acenaphthane | <1.0 *ppb | ND** | ND** | <0.5***ppb | 1 | <0.5 |
| Fluorene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.5 | <0.5 |
| Phenanthrene | <1.0 *ppb | 0.06** | ND** | <0.5***ppb | 2 | <0.5 |
| Anthracene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.1 | <0.5 |
| Fluoranthene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 1 | <0.5 |
| Pyrene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.2 | <0.5 |
| Benzo(a)anthracene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.1 | <0.5 |
| Chrysene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.2 | <0.5 |
| Benzo(b)fluoranthene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.2 | <0.5 |
| Benzo(k)fluoranthene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.5 | <0.5 |
| Benzo(a)pyrene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.5 | <0.5 |
| Dibenzo(a,h)anthracene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.5 | <0.5 |
| Indeno(1,2,3-cd)pyrene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.5 | <0.5 |
| Benzo(ghi)perylene | <1.0 *ppb | ND** | ND** | <0.5***ppb | 0.5 | <0.5 |

*Limit of Quantitation = 1.0 for all chemicals - Lancaster Laboratories
**Limit of Quantitation - Lancaster Laboratories
***Minimum Detection Limit - CHPPM Laboratory
Note: Detection limits may vary due to the difference in methods used for analysis.

**Table B12. Metals data, LANDA treatment system.**

| Date | Source | Copper (Cu) | Cadmium (Cd) | Lead (Pb) | Nickel (Ni) | Chromium (Cr) | Zinc (Zn) | Silver (Ag) |
|---|---|---|---|---|---|---|---|---|
| 4-Nov-96 | Stored Water | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.05 |
| 4-Nov-96 | Tap Water | 0.307 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.05 |
| 2-Dec-96 | Stored | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.185 | <0.05 |
| 29-Dec-96 | Stored | <0.05 | 0.083 | <0.05 | <0.05 | <0.05 | 0.58 | <0.04 |
| 27-Jan-97 | Stored | <0.05 | 0.176 | <0.10 | <0.05 | <0.05 | 1.40 | <0.04 |
| 26-Feb-97 | Stored | <0.05 | 0.104 | <0.10 | <0.05 | <0.05 | 0.805 | <0.04 |
| 25-Mar-97 | Stored | <0.05 | <0.10 | <0.05 | <0.05 | <0.05 | 0.473 | <0.02 |
| APGR 200-41 Metals, PPM | | CU 3.38 | Cd 0.69 | Pb 0.69 | Ni 3.98 | Cr 2.77 | Zn 2.61 | Ag <0.2 |

Table B13. Alkalinity data, LANDA treatment system.

| Date | Source | Total Alkalinity mg/L $CaCO_3$ | pH |
|---|---|---|---|
| 18-Nov-96 | Stored | 44 | 6.4 |
| 25-Nov-96 | Stored | 27 | 6.3 |
| 2-Dec-96 | Stored | 22 | 6.4 |
| 9-Dec-96 | Stored | CHPPM 44 ATC 42 | CHPPM 6.6 ATC 6.7 |
| 16-Dec-96 | Stored | 28 | 6.4 |
| 23-Dec-96 | Stored | 28 | 6.8 |
| 29-Dec-96 | Stored | 33 | 6.6 |
| 6-Jan-97 | Stored | 33 | 6.6 |
| 13-Jan-97 | Stored | 34 | 6.6 |
| 21-Jan-97 | Stored | 34 | 6.2 |
| 27-Jan-97 | Stored | 18 | 5.7 |
| 26-Feb-97 | Stored | 47 | 6.5 |
| 25-Mar-97 | Stored | 177 | 6.8 |

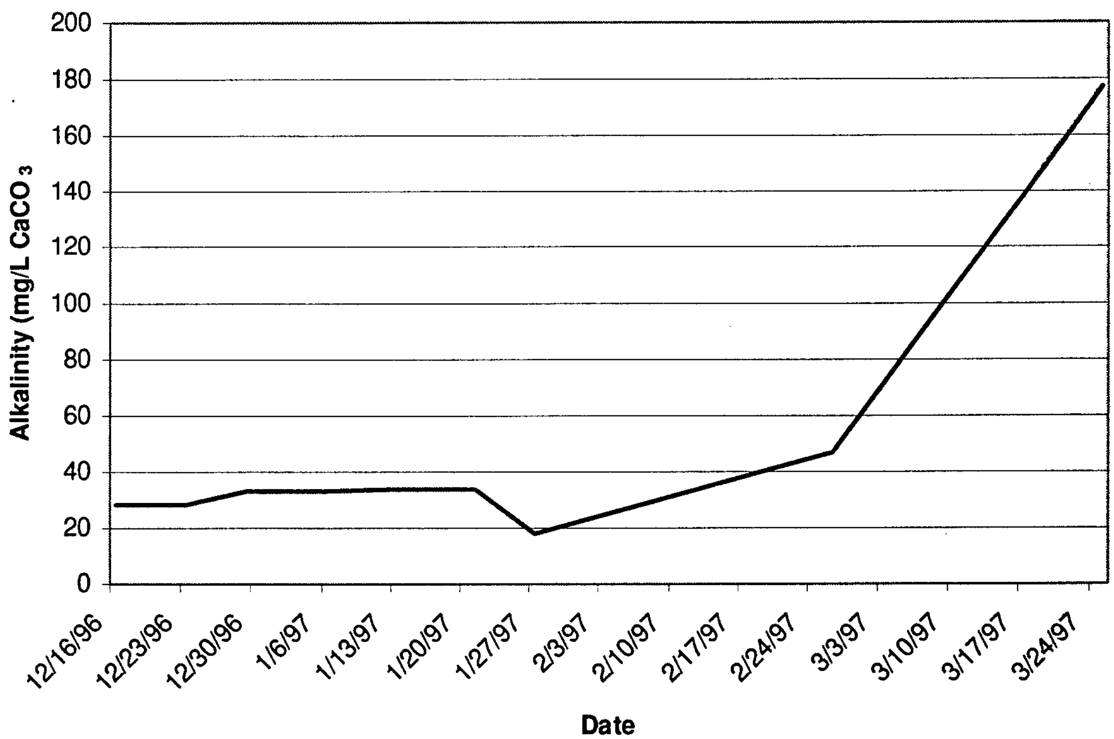


Figure B3. Alkalinity vs. time, LANDA treatment system (corresponds to data listed in Table B12).

Table B14. Hardness data, LANDA treatment system.

| Sample Number | Env. Number | Sample Date | Sample Source | Hardness mg/l CaCO3 | Calcium mg/l | Magnesium mg/L |
|---|---|---|---|---|---|---|
| 17679 | 1929A | 18-Nov-96 | Stored | 77.5 calc | 21.2 | 5.97 |
| 17715 | 1936 | 25-Nov-96 | Stored | 92.3 calc | 24.5 | 7.57 |
| 17762 | 1944A | 2-Dec-96 | Stored | 75.9 calc | 20.7 | 5.87 |
| 17792 | 1951C | 9-Dec-96 | Stored | 103.0 calc | 28.6 | 7.73 |
| 17844 | 1960A | 16-Dec-96 | Stored | 149.7 EDTA | 47.7 | 9.7 |
| 17898 | 1964A | 23-Dec-96 | Stored | 187.2 EDTA | 60.2 | 10.4 |
| 17899 | 1971A | 29-Dec-96 | Stored | 201.5 EDTA | NT | NT |
| 17902 | 1979 | 6-Jan-97 | Stored | 173.4 EDTA | NT | NT |
| 17984 | 1984 | 13-Jan-97 | Stored | 125.6 EDTA | 39.1 | 6.80 |
| 17992 | 1990A | 21-Jan-97 | Stored | 189.3 EDTA | 57.3 | 11.2 |
| 18010 | 1995A | 27-Jan-97 | Stored | 102.9 EDTA | 29.6 | 7.09 |
| 18234 | 2038 | 26-Feb-97 | Stored | 150.7 EDTA | 44.2 | 9.76 |
| 18989 | 2058 | 25-Feb-97 | Stored | 181.2 EDTA | 53.6 | 11.5 |

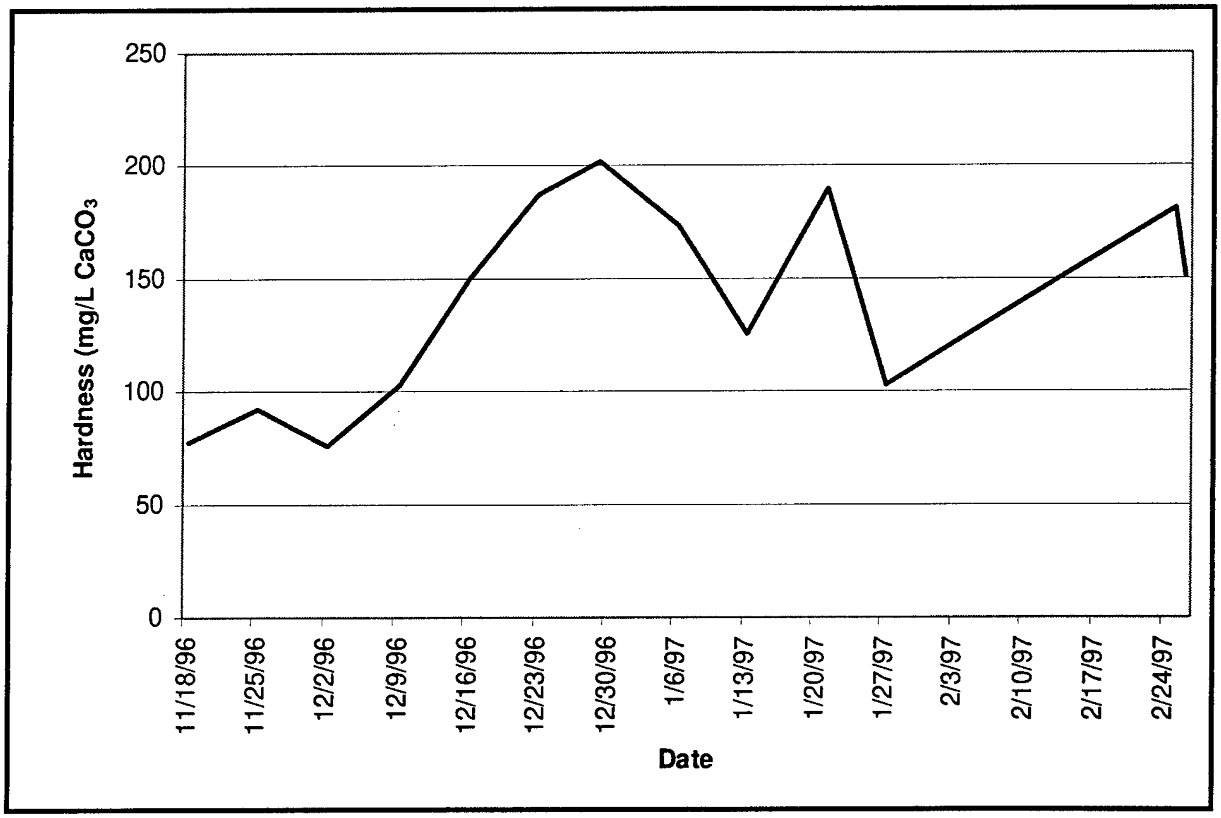


Figure B4. Hardness vs. time, LANDA treatment system (corresponds to data listed in Table B13).

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